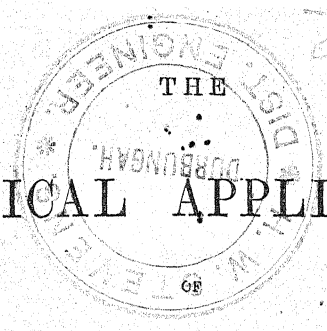


THE PRACTICAL APPLICATIONS OF ELECTRICITY.

A Series of Lectures

DELIVERED AT

THE INSTITUTION OF CIVIL ENGINEERS,

SESSION 1882-83.

LONDON:
Published by the Institution,
25, GREAT GEORGE STREET, WESTMINSTER, S.W.
1884.

ADVERTISEMENT.

The Institution as a body is not responsible for the facts and opinions advanced in the following pages.

LONDON: PRINTED BY WM. CLOWES AND SONS, LIMITED, STAMFORD STREET AND CHARING CROSS.

PREFACE.

In the Report of the Council submitted to the Annual General Meeting in December 1883, it was stated that, as far back as 1868, a suggestion had been made for the establishment of Readerships for the benefit of young Engineers. That idea was not carried out, as the organisation of Supplemental Meetings, for the reading and discussion of Papers by Students of the Institution, was deemed preferable, and to be more in accordance with the usages of the Society. In August 1879, the expediency of having, in addition to the Ordinary Meetings, Lectures on special subjects of engineering was mooted. It was felt that if a limited number of lectures could be arranged in each session, to be delivered by men of eminence, not on the elementary subjects of the class-room, but on the principles involved in the action of the "Great Sources of Power in Nature," and their practical applications, the provisions of Section xiii. of the By-laws would be met in a proper manner. In March 1882 it was resolved to give effect to this proposal, and arrangements were made for a course of six lectures, by as many lecturers, on the "Practical Applications of Electricity." As, however, the Session 1881–82 was then far advanced, it was decided to postpone their delivery until the Session 1882–83, when the lectures included in this volume were given. All the lecturers were Fellows of the Royal Society, and Members of The Institution of Civil Engineers,

and in every case their services and those of their assistants were afforded gratuitously.

The Council feel assured that the members will fully appreciate the amount of time and labour bestowed in the preparation of these lectures, and the value and importance of the information thus communicated.

These lectures were so successful, that a second series on "Heat in its Mechanical Applications" has been arranged for the Session 1883–84. This course will also be issued to the members in a separate volume.

CONTENTS.

15 *February*, 1883.

PAGE

THE PROGRESS OF TELEGRAPHY. BY W. H. PREECE (1 plate, 2 woodcuts) 1

1 *March*, 1883.

TELEPHONES. BY SIR FREDERICK BRAMWELL (15 woodcuts) 26

15 *March*, 1883.

THE ELECTRICAL TRANSMISSION AND STORAGE OF POWER. BY DR. C. W. SIEMENS (1 plate, 5 woodcuts) 56

5 *April*, 1883.

SOME POINTS IN ELECTRIC LIGHTING. BY DR. J. HOPKINSON (12 woodcuts) 81

19 *April*, 1883.

ELECTRICITY APPLIED TO EXPLOSIVE PURPOSES. BY PROFESSOR F. A. ABEL 107

3 *May*, 1883.

ELECTRICAL UNITS OF MEASUREMENT. BY SIR W. THOMSON 149

INDEX 177



THE

PRACTICAL APPLICATIONS OF ELECTRICITY.

15 February, 1883.

JAMES BRUNLEES, F.R.S.E., President,
in the Chair.

The Progress of Telegraphy.

By WILLIAM HENRY PREECE, F.R.S , M. Inst. C.E.

Mr. PRESIDENT AND GENTLEMEN,—It is my misfortune, and not my fault, that I have to lead off this course of lectures on the Practical Applications of Electricity. It is my misfortune because it happens that Telegraphy is the oldest and the first of these practical applications, and though it is the oldest and the first, nevertheless it is very young, for it dates its birth only from the year 1837. The great shining lights of this Institution were present at its birth. Robert Stephenson, Isambard Kingdom Brunel, Joseph Locke, and George Parker Bidder, were its godfathers. There are many (and doubtless there are some present to-night) living members of this Institution who assisted materially in its delivery. It grew around our railway system, and our railway managers were not slow in detecting the power that telegraphy gave them to marshal their trains, to adjust their traffic, and to protect life. In 1851 this art, if I may so call it, had scarcely commenced to take a commercial existence, but now it is only necessary to refer to the map to see to what an enormous extent telegraphy has grown.

A Civil Engineer would feel himself disgraced if he knew nothing of the strength of materials, of the pressure of liquids, of stresses and strains; but how many amongst my hearers are there who know much of electromotive force, of resistance, of currents, of volts, of induction, *et hoc genus omne.* An American Author has told us that it is very dangerous to prophesy unless you know; but I think I am justified in prophesying this, that it will not be very long before these terms become household words, for they have already been admitted into commercial, legal, and Parliamentary lore.

Now, gentlemen, what is electricity? Electricity, as we know it and use it, is a mere form of energy; it is brought into existence when it is wanted, and it disappears when it has done its duty. "Like the snowfall on the river—a moment white, then melts for ever." Like sound and light and heat, electricity is a mere abstract idea; it has neither substance nor shadow. Supposing I take a match-box, and out of that box I take a match, is there any man in this room who would say that in the head of that inert match we have light and heat? And yet when I strike that match we excite both heat and light. Would anybody say that in this bell I have sound? And yet when I strike that bell I produce sound. So, when I take a piece of zinc, will anybody tell me that in that zinc there is electricity? There is something, for the moment when I put this zinc into that battery, I have started something going, the bell rings violently; and the moment I take that zinc out, that something has ceased, for the bell becomes silent again. This zinc contains what the match contains, what my blow produced—energy; and it has simply been the conversion of this energy, first into one form producing chemical action, then into another form producing electric currents, then into a third form producing magnetic power, which produced that other form—sound, which made that bell audible to you all. Now, much brain-wasting power has been devoted in trying to picture some conception of this thing called electricity, but we cannot conceive the existence of that which does not exist. That which exists is energy, indestructible, convertible, and we in our practical applications merely utilize it in its electrical form. My duty to-night is to show you how we employ this particular form of energy and transmit it to the uttermost parts of the earth, there to do work, to express our wishes and our wants.

Now, this electrical form of energy possesses certain properties. It is found in a *potential* or passive state, and in a *kinetic* or active state. We have *electromotive force*, a term that is simply analogous to "head," when we speak of water, "pressure," when we speak of gases, "temperature," when we speak of heat; electromotive force in fact is simply a term analogous to difference of level, to the difference of potential energy that determines the flow of liquids. When we possess this difference of potential or electromotive force, we can produce a *current*, or the kinetic form of electrical energy, provided we supply a path for this flow of energy. It is impossible, with the materials at our command, to find anything that does not more or less oppose or resist the flow of electricity. Hence, materials possess what is called *resistance*, and electromotive force and resistance are expressed in definite

magnitudes; they can be measured with greater exactitude than any other system of magnitude at the command of the engineer. The engineer can measure feet and inches and the thousandth part of an inch, but the electrician can measure the millionth part of an inch; in fact there is no magnitude or force in Nature that can be practically measured with greater exactitude and in more minute dimensions. The unit to which electromotive force is referred is called the *volt*, and that to which resistance is referred the *ohm*, while the unit current is called the *ampère*. The great progress that has been made in telegraphy, and the great advances that have been made in the science of electricity, are due to the power that this system of exact measurement has given the engineer.

Now, having at our command this form of energy, and being able to overcome resistance by its means and transmit it to a distance, the question arises, How is it produced? It is produced in nearly every form of telegraph by the simple combustion of zinc, in either sulphuric acid or some solution in which sulphuric acid bears an intimate part. There are exceptions. We have sodium chloride, and there are other liquids, but practically and generally the form of chemical action which takes place is the conversion of zinc into zinc sulphate. Now, without running you through the elementary details of the voltaic cell—a matter absolutely impossible within the hour and a half devoted to the subject—I may simply briefly point out to you the forms which these different batteries take. We have first Daniell's. In Daniell's zinc is consumed, copper is deposited, and we have a normal electromotive force that is very closely allied to our unit, the volt. But the Daniell battery has one serious defect, and that is, it works out quicker when it is idle than when it is at work—there is a considerable local action that very speedily destroys its efficiency. But Leclanché, in Paris, introduced a battery utilizing zinc acted upon by chloride of ammonium, and peroxide of manganese, in contact with coke, by which he succeeded in stopping, not only the local action, but he gave us an electromotive force 50 per cent. greater, so that ten of these Leclanché cells are equal to fifteen Daniell's. But we have gone a step further than this, by utilizing Poggendorff's discovery of the power of bichromate of potash. The result is we get a battery whose electromotive force is nearly 50 per cent. that of Leclanché, twice that of Daniell's, and one that gives us an efficiency that is simply marvellous for telegraphic work. Now, of these cells in our Post Office Department, we have 87,221

Daniell's, 56,420 Leclanché's, 22,000 bichromates; altogether we have about 165,000 cells; and by a rough calculation of the number of batteries in use throughout Europe, at the present moment, they exceed 1,200,000. There are other forms of apparatus by which we produce these currents. The mere movement of a coil of wire in front of a magnet causes those currents that are so powerful in producing the electric light, and by simply turning a handle in this way I am able, by rotating a coil of wire in front of the magnet, to create currents powerful enough to ring that bell.

Great improvements have been made in the form and efficiency of these batteries, by the application of scientific laws to the investigation of their performances; and, owing to the progress that science has made, it is quite possible to maintain batteries in a state of constant efficiency that ten years ago was absolutely impossible. By the aid of rigid tests, and by the aid of accurate instruments, we are able to maintain them, in their full state of perfection without ever deteriorating more than 25 per cent. below their normal value. The only defect that the bichromate battery has developed is a deteriorating influence on the health of the men attending to them, due to the action of mercury. Very promising experiments are being made with secondary batteries which will probably diminish this evil in all large centres.

The production of these currents of electricity being so simple and easy, the next question that arises is, How are they conveyed from place to place? We find materials divided into two classes—*conductors* and *insulators*. The conductors are materials which are transparent, as it were, to this flow of energy, and insulators are materials which are opaque; conductors offer comparatively small resistance, insulators offer great resistance. Copper is one of the best conductors; glass, porcelain, gutta-percha, are some of the worst, and therefore they are very good insulators. The first telegraphs were laid underground. Here is a piece of a telegraph of five wires, erected between Euston and Camden, and buried underground—creosote timber, or prepared timber, with copper wire let into grooves and covered with a tongue. We call it the "fossil" telegraph. But it was speedily found that copper buried in that way could not be maintained in a condition of insulation, and therefore wires were put overground, attached to poles and insulators. In England, hitherto, we have invariably used wood creosoted, to check decay. Abroad, and in the colonies, iron is used to a very great extent, and to my left here I have one of the best—perhaps the best—iron

pole that has been produced, that of the Messrs. Siemens, fitted up with insulators complete, so that you may see the form that experience has now taught us that iron should take to secure the greatest efficiency. Insulators are of all shapes and forms and sizes. Every man who has had anything to do with the advance of electricity has had a shot at a new insulator, and the result is that they are as numerous as the men who have been in power. But by dint of careful examination of all those in use throughout the world, and with the knowledge that it is essential to produce an insulator that shall be readily cleansed, this that I hold in my hand is now the form that is most generally adopted in England and India, and throughout our colonies. There is a very curious meteorological effect that we have to protect ourselves against in England, and I think England is peculiar in this respect, and for that reason the problem of insulation in England is more difficult than in any other country. The reason is this, that in England the prevailing winds blow from a warm climate to a cold one, while on the coast of America they blow from a cold climate to a warm one. Now, coming from a warm climate to a cold one, the result is that aqueous clouds speedily deposit their moisture upon anything in their progress colder than themselves, and the result is that the insulators become coated with a film of moisture—a film that is so dangerous in its consequences that sometimes the whole telegraph system of England has very nearly broken down.

The conductors are almost invariably iron, and within the last few years very great improvements have been made in the manufacture of iron wire. The improvements are so great that in the present day wire is exactly 50 per cent. better than it was seven or eight years ago. The No. 8 wire of the present day is as good as the No. 4 used to be. Again, wire is manufactured in long lengths; there are no welds, no joints—sources of enormous trouble in the early days of telegraphy. It has great ductility, it has considerable durability, but in the neighbourhood of smoky towns, such as London, Manchester, and some of the places in the north, the decay of iron wire is very rapid. We have coated it with certain materials to try and check this decay. Those who are in the habit of travelling on the London and South-Western Railway may notice between Waterloo and Nine Elms that the material we used to preserve the iron has itself gone. It hangs in unpleasant festoons on the wire, and it was only a few weeks ago that I was asked what was that fungus that grew on the South-Western wires. The improvement in iron is so great that wire which had a breaking strain of some 25 to 30 tons now has a breaking

strain of 40 to 50 tons; and wire is absolutely made for submarine cable purposes, and for long spans, with a breaking strain of 90 tons to the square inch. Copper, which is much used in districts where iron rapidly decays, has also followed in this train of improvement, and it is remarkable what variation has been found in the quality of copper. Five specimens of copper,

Samples of Copper.	Conductivity.		
	1st Test.	2nd Test.	3rd Test.
A	101·4	101·1	101·02
B	44·7	44·87	44·51
C	98·7	99·63	98·64
D	101·3	100·2	101·14
E	18·7	18·63	..

taken at random, were submitted to three individuals to test, and you will see that while the three individuals agreed almost exactly in their measurements, the copper varied, 100 being the standard of purity,[1] from 18 per cent. to 101·4, or more than purity. The specific conductivity of the copper of commerce, unless checked and controlled by electrical tests, is liable to give those extremes of 44 and 101. Fortunately in telegraphy our tests are so simple that we can tell with absolute certainty the quality of the material we have; and now it is excessively rare to obtain copper for telegraphic purposes that gives less than 96 per cent. of pure copper. Compound wire, that is a small steel wire surrounded either mechanically or electrolytically by copper, has been experimentally used, but not with much success. Wire made from phosphor and silicious bronze is coming much into use, and it is a very promising material. The latter has the strength of iron, and the conductivity of copper, and if it only stands the test of time it will serve to supply a very serious want. We find now, owing to the multiplicity of wires, that our poles will not carry any more; and if any material with lightness and strength can be produced which will enable our poles to carry twice as many wires, it will be a valuable adjunct to telegraphy.

Wires are carried underground by means of gutta-percha, and the same improvements exactly that have been made within the

[1] Dr. Matthiessen's standard was 100 inches of annealed pure copper, weighing 100 grains, having a resistance of 0·1516 ohms at 60° F. I am indebted for the above Table to Mr. Willoughby Smith.

past few years in iron have also been made in gutta-percha. The insulating qualities, the inductive capacity, the durability, and all other points, are gradually improving. We find that gutta-percha meets with enemies underground — wretched, horrible little insects that you cannot see with the eye, and can only detect with the microscope, make fine meals out of this coating of our wires, and produce considerable mischief. Vermin, mice, rats, seem to have a *penchant* for gutta-percha, so that the troubles we have are very great; but, nevertheless, gutta-percha as an insulator for telegraph purposes remains the very best material at our command. We have in England no less than 12,000 miles of underground wire, and the cry is very often raised that we ought to put all our wires in England underground. Those who make that cry do not know the difficulties that deter us from carrying that out. In the first place, the cost of putting wires underground is four times the cost of putting them overground. Next, the capacity of wires underground is only one-fourth that of wires overground, in consequence of a curious retarding influence upon the currents that slows the operations of telegraphy. The result is that whenever we take into consideration any long length of underground wire, as, for instance, between London and Leeds, or London and Manchester, underground wires are commercially sixteen times worse than overground wires. You can readily therefore imagine that the authorities of the Post Office are not particularly anxious to put wires underground. We shall be very glad to do so if the Legislature will find the capital for the purpose, and the amount required to replace our system underground is only £20,000,000! Now this cry for underground work has arisen from certain snowstorms that have occurred recently. Snowstorms and their effects, like a great many other things, are very much exaggerated by the press. The press naturally makes a fuss at any rupture of communication, for it checks the news transmitted, but we always find that a snowstorm is a very fine thing to improve our traffic, for generally speaking, whenever a snowstorm has taken place, our traffic has increased at least 50 per cent. On the occasion of the great snowstorm of January 19th, 1881, the messages at the central station, which averaged 40,000 a day, sprang up to 60,471.

With regard to submarine telegraphy, I have only to refer to the map for you to form some idea of the enormous network of telegraphs that extend all over the world, and which has brought the uttermost parts of the earth into intimate union with London. We have now no less than nine cables crossing the Atlantic—eight

in the North Atlantic, and one in the South Atlantic. We have cables coming around the Peninsula, along the Mediterranean, down the Red Sea, across the Indian Ocean, away through the Archipelago to Australia, and from Australia to New Zealand. From Singapore they go northwards through Hong Kong to Japan, and away through China and Russia back to England. We have wires coming down through the West Indies to the Gulf of Mexico, and connecting the West Coast of America. The result is, that there is scarcely a spot throughout the whole world that is not in intimate connection with England. To carry out this tremendous undertaking £30,000,000 have been expended, and there are no less than 80,000 miles of cable at the bottom of the ocean. I remember twenty-three years ago reading a Paper[1]—my first Paper—before this Institution, and I ventured to promulgate the unheard-of doctrine, that we ought to make ourselves as acquainted with the bottom of the ocean as we were with the surface of the land. The President of that evening—not always distinguished for his courteous manner—gave me a very severe rebuff for daring to promulgate such an outrageous notion before this Institution. But, gentlemen, we have since sent ships to every sea. Her Majesty's ship "Challenger" has spent three years in surveying the depths of the ocean. She has found that there is "a life," and a real life, "in the ocean wave," and "a home in the rolling deep," and she has found that the deep "unfathomed caves of ocean" do bear "gems of purest ray serene," and she has brought back to us a knowledge, not only of the life of the ocean, but of the nature of the bottom, so that we can now say that we know more of the depths of the ocean than we do of the surface of many a continent on this globe. The result is, that cables are now designed to suit every depth and bottom, and the operation of laying a cable has become a simple matter. The Telegraph Construction Company who laid, not the last cable, but the cable, I think, of 1880, across the Atlantic, succeeded in laying it without any hitch, without any stoppage, in the incredibly short space of twelve days. Again, repairs of cables have become equally a simple matter. A fleet of twenty-nine ships is maintained in different parts of the world to keep our cables in order. The cables can be brought to the surface from any depth. The 1869 cable, of which I have a specimen here, was brought to the surface from a depth of 1,940 fathoms and re-

[1] Minutes of Proceedings Inst. C.E., vol. xx., p. 26.

paired; that cable is now thirteen years old, and is working as well as on the day after it was laid. A cable in the Bay of Biscay has been picked up from a depth of 2,700 fathoms and repaired. I am therefore justified in saying that cables have become a solid property, and that their age, their estimated age, has increased considerably from what we took it some few years ago, namely, ten years, to certainly fifteen or even twenty years, and British capitalists are now justified in investing their money in such enterprises as this map displays, which I look upon as one of the greatest glories, if not the very greatest glory, of British enterprise.

We have some remarkable accidents in cables. You would scarcely conceive it possible that a cable could be destroyed by fire; yet we have had an instance where a cable was destroyed by fire. Some idle boys lit a bonfire on the beach immediately over the shore end, and the heat melted the gutta-percha and broke it down. We have had a cable broken by a bull; a mad bull rushed vehemently down the streets of Yarmouth in the Isle of Wight, into the harbour and got entangled amongst the wires there, and broke a submarine cable. In the Indian Ocean a cable was found broken, and when they went to repair it they brought up a whole whale. The whale had got entangled in the wire. The whale was dead, and so was the cable. Again, we find little treacherous animals attacking wires, such as teredos, zylophaga, limnoria, and a few other little creatures of that character, which bore into the cable, reach the copper wire, and break down the cable, and the result is, that strenuous measures have to be taken to protect cables from these villainous opponents. The cables that are now laid in depths liable to the action of these teredos are armour-plated; the gutta-percha is coated with a thin taping of brass, and microscopists and physicists have yet to find a little wretch that will pierce its way through brass. Now, gentlemen, I ought to have shown you certain specimens of cable; but you all know what a submarine cable is, and as there are plenty of specimens before you, for which I am indebted to the Telegraph Construction Company, the Gutta-Percha Company, the Silvertown Company, and others, you will see there, in various forms, the character of the conductor now in use.

I have shown how electric currents are conveyed from place to place. I want now to show how we can utilize these currents at distant places to appeal to the consciousness. An electric signal can appeal to the consciousness, either through the eye, or through the ear. If the atmosphere of this room will only behave itself, I will

show how we utilize one fact of electricity to produce effects; but let me assure you, that the vagaries of that needle before me at the present moment, are not due to electricity; they are due to certain currents of air that are flying about the room. However, perhaps I may be able to eliminate from the motion due to the currents of air, the motions due to electricity. I want to show you, that whenever a wire, conveying a current of electricity, passes in the neighbourhood of a magnet, it causes that magnet to take up a position at right angles to the wire. This is the main and simple fact upon which most of our early telegraphs were based, and also upon which most of our present measuring apparatus are founded. Now this gutta-percha wire passes immediately over that magnet, and we have a battery underneath. When I bring these two wires together, you will observe the effect (illustration). It was not air, it was a current of electricity which produced that effect, and I will make him go back again. You will see that when I bring these two wires into contact, I produce a deflection of that needle. Well, that is the simple fact; but it will show, perhaps, better on these little instruments (single-needle telegraphs) before me. When I move this handle, I send a current of electricity around the magnet inside there, and I produce, as you see, an effect. Now, when I send the current in the other direction, I produce an effect on the other side, and then, by combining these two facts in different orders, we are able to form an alphabet, and convey words by spelling each letter—the letter A is that, B is that, and so on throughout the whole alphabet. The first and earliest instrument was this. It is not a Greek temple; it is one of Cooke and Wheatstone's original double-needle instruments—very pretentious in its appearance. In its day it was most useful. I can remember the time very well when, in order to make these needles work, we had to perch a little messenger-boy astride on the top of this Greek temple, with a large magnet in his hand, in order to keep the needles steady. In the progress of scientific thought, the causes of that vibration, that interfered so much with our reading, were speedily found out and eliminated, and the result was the double-needle instrument was converted into the particular form that is known as the single needle which is found now in every railway station. There are in the Post-Office no less than 3791, and in the railway service of this country, 15,702; so that we have 19,000 of these little single-needle instruments in this country, carrying on the traffic of our railways and conveying wishes and thoughts from place to place.

The second effect that is utilized for telegraphic purposes, is the simple fact, that if you take a mass of iron and surround it with wire, sending a current of electricity through the wire, you convert that piece of iron into a magnet. Without electricity, I may move this piece of iron amongst those nails, and the effect is *nil;* but with electricity, the effect is very different, the nails are attracted and cluster about each other in a very striking way, but the moment I take the current away, the effect disappears. You see the moment I transmit the current through the coil, we have magnetism strong; the moment I take it away, the magnetism ceases.

In order to produce sounds, in order to ring a bell, it is only necessary to imitate the motion of the hand. Supposing I want to strike that bell, I merely give a little joint movement, and I strike that bell, and produce some sound. Now let me put my magnet there, and in front of that magnet I place a little bar of iron jointed, instead of the rough and uncouth nails, and you will see that whenever I send my current through the coil, I produce an attraction. You see how easy it is to put on that iron bar a little hammer, and in front of it something that will emit sound, and there I produce a sound. By the bye, let me show you how to make a bell ring, because there are many of you interested in railways, and you will see how simple it is to produce the sound of a bell. You see, by the effect of currents, I simply reproduce the movement of my wrist. Those two effects that I have shown you are the basis of all telegraphs, or nearly all, that exist at the present day. Either we avail ourselves of the deflection of the needle, or we avail ourselves of the production of magnetism. We have the simplest form of telegraphs known in Wheatstone's A B C, of which there are 4398 in use in the Post Office. There the simple rotation of a needle propelled by currents, causing it to dwell opposite the letter that you want to indicate, enables you to spell out a message; you simply rotate a handle and work some finger-keys, and the result is you are able to cause a little index to dwell opposite any letter of the alphabet you wish to send, and any child or any old woman can work it; but the rate of working is rather slow, and this instrument is gradually being replaced now by an instrument that will be brought before you the next time we meet, called the telephone.

Acoustic reading—reading by sound—is the advanced character of the telegraphs of the present day. We commenced with a slow and cumbrous double needle; we passed to the single

needle, and about the year 1852 one or two various classes of apparatus were designed and devised by Mr. Henley, by Sir Charles Bright, and his brother, and by others. Many companies were formed to carry these out; and when the telegraphs were bought by the State there was the survival of the fittest; the best adapted were selected, and the result is that at the present time we have the A B C for small stations; the single needle for bigger stations, and, where real business involving a skilled staff is required, we come to the acoustic instruments. One of the earliest is the "Bell," of the brothers Bright, and here we read by an alphabet formed of two sounds, differing in tone or pitch. That is one sound; that is another sound; and thus the alphabet is formed; so that you have the whole of the letters of the alphabet formed by a mere succession of sounds, each combination of sounds itself distinctly indicating its character as clearly as we say A, B, or C.

This system of acoustic reading has passed through several stages to the instruments we use at the present day. Morse invented the alphabet that is used. Morse's instrument was first employed in America; it came over to this country and to the Continent, and at the present moment, while there are 1,330 Morse instruments in use in England, there are over 40,000 in use on the Continent. The best form is that produced by the house of Siemens, where the characters of dots and dashes are imprinted in clear ink upon a paper strip. Here is the paper strip, and the paper passes through this instrument, and the characters are depicted upon it in a way I shall show you presently. But it was very soon found that the dots and dashes that were made by a magnet like that, conveyed to a man's ear by their sound precisely the same idea that they conveyed to his eye by the marks they make; he could detect by the ear precisely what was wanted, and sound-reading came in not by invention, but by accident, or by a combination of the two. The instrument broke down; the little magnet continued its work, and the skilled clerk was able to carry on the work by his ear. The result has been that these instruments are simplified in their character; they are more expeditious in their action; they are more accurate, and the rate at which they work is simply the speed at which a man can write. The sounder is an importation from America, where scarcely any other form of instrument is used. In 1869 there were none in England, now there are 2,000. On the Continent there is scarcely one! Now we have got wires brought into this room; one I hope goes to Birmingham; the other may go—I don't know where, but we shall find out directly.

(Mr. Preece then told his assistant to ask for an alphabet from the Central Station. The alphabet was sent so that every one in the hall could hear it.)

You have seen, from the actual operation of reading by sound, how the alphabet is made up by dots and dashes. Although I said that that instrument is distinguished by its great accuracy, nevertheless I do not pretend for one moment to say that it is not inaccurate. Errors are inherent to telegraphy, and, do what we will, errors cannot be avoided. The personal equation enters very largely into telegraphy. A telegraphist is in the position of not seeing what he writes, and of not hearing what he says, and therefore he is in a very much worse position than we who see what we write, and hear what we say. And yet how many of us are there in this room who can write for a very long time without making a mistake, or who write a signature that is legible all over the world? In order to prepare myself for this lecture I communicated with every railway company in England. I was labouring under the delusion that my name was pretty well known amongst the railway world at any rate, but I found I was mistaken when I got a letter back addressed "W. H. Keene." It came back addressed "W. H. Green"; it came back addressed "W. H. Greer"; but the worst blow of all was to receive this letter addressed "W. H. Piller"! Now if an accurate and beautiful writer like myself has his signature so mistaken, you cannot fail to comprehend why telegraphists make mistakes sometimes. The mere loss of a dot may cause a mistake. For instance—you have all heard the story perhaps, but it is so good that I cannot resist telling it again: a party of young ladies from a school went to a certain place, and the schoolmistress was very anxious to know of their arrival, so the message was sent, "Arrived all right;" but the schoolmistress received the message, "Arrived all tight!" Now, gentlemen, when the mere loss of a dot occasioned that, you can readily understand how mistakes arise. There was another one that perhaps many of you here may understand. A message was sent, "Five fathoms of eight feet will do;" it was received, "Five fat sows of eight feet will do." Now, there is scarcely any difference whatever between "fathoms" and "fat sows" except a short pause. I could go on all night telling you these stories, but I have come not to amuse but to instruct you. I want to point out that the progress made in the applications of electricity to commercial purposes has been followed by progress in the character of the apparatus used, in the mode of working, and in the efficiency of the staff employed. Careful specification, exact measurement,

sound workmanship, and rigid inspection, have given to telegraphic apparatus a character that I defy any other workmanship in the world to surpass. Cheap and nasty are synonymous terms in telegraphy. There are on this table instruments that, in construction, in design, and in workmanship, will bear comparison with the finest chronometers that were ever produced. The progress of telegraphic apparatus is an admirable example of growth by cultivation, of evolution by scientific selection, and of the survival of the fittest.

We have introduced various modes of working, but of all the machines the one that is used to the greatest extent on the Continent, and which in design and workmanship will equal any of them, is the beautiful type-printing apparatus of Professor Hughes. The instrument is used exclusively by the Submarine Company between England and Europe, and as an international instrument all over Europe. It is worked direct between Paris and Constantinople. There are three or four thousand of these instruments at work. We have one here, and I will ask that the alphabet be sent. Now, in this instrument we have letters and words reproduced in bold Roman type, and doubtless many of you who communicate with the Continent receive messages printed in this bold and legible character. After the lecture is over we will have many slips printed, and you will have the opportunity of seeing it in working order. I should like to have spoken of the instruments used in our exchanges and clubs to record news and the price of stocks, and I should like to have spoken of Sir William Thomson's beautiful siphon-recorder that is used on all long submarine cables; but the clock in front of me tells me that I am like many trains in this country—rather lagging behind my time; so I must resist the tendency I have to dwell on many of these things, and run rapidly through my programme.

In the instruments I have shown you, and in the mode of working you have seen, we have what is called simple telegraphy. I want to show you how we can work duplex, that is, instead of sending one message in one direction we can send two messages at the same time in opposite directions. This is one of the simplest of the phenomena that we use, and one that I have very strong hopes of being able to make you understand. For that purpose I have here two instruments, and they are in connection with each other, so that when I move one needle the other is deflected; when I send a current of electricity from here to there I move both those needles; when Mr. Cooper sends a current

of electricity to me he also moves both those needles. Now I want to make use of this simple fact, that when I send a current of electricity to the other station at the same moment that he sends a current of electricity to me, these two currents neutralise each other, and nothing whatever passes upon the wire. Many people imagine that in duplex telegraphy currents pass each other. Nothing of the sort. Nothing whatever passes; we utilize the fact that the wire is neutralised and that nothing passes. When I move my needle I want to so arrange my needle that my own current shall not affect it, and for that purpose the needle is surrounded with two wires, through one of which the current goes in one direction, and through the other the current goes in the reverse direction; so that if I make those two currents exactly equal I shall obtain neutrality for my needle—now you see I have not got neutrality—but by putting resistance in I at last get to a point when my needle is not affected but the other one is. I will ask Mr. Cooper to adjust his in the same way. Those two instruments are now so adjusted that while he is working his, mine only is affected, and while I am working mine his only is affected. Why is this? Because I have two currents going around my needle in opposite directions, and he has the same; but if we check or neutralise one of those currents the result is that the other will act. Every time he moves his handle I may move my handle; we do not affect each other in the least. I keep sending dots, he sends something else, and the result is that he can cause my needle to move as he pleases, and I can cause his needle to move as I please, and it is simply owing to the fact that we utilize the neutralisation of currents to produce effects at our own station. We have a wire here that goes to our central station, and I hope to be able to show this system of duplex telegraphy working in actual operation. We have got Birmingham here. You see duplex working between this room and Birmingham. [A message was sent while one was being received.]

When you send messages in opposite directions at the same time you have duplex working; you can however send two messages in the same direction, though you cannot send two currents in the same direction at the same time. You can, however, send currents which shall vary in direction, and currents which shall vary in strength, and you can have one instrument that will record its marks by any change in direction independent of strength as well, or you can change the current in its strength whether it goes in one direction or the other, and you can make an instrument respond to changes of strength independent of direction; so that

you have one instrument responding to change of direction, and another instrument responding to changes of strength.

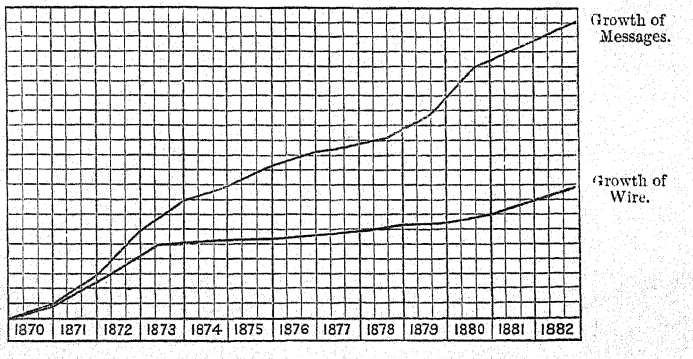
That leads me to diplex working—two messages going in the same direction at the same time. Well, if you can have two messages going in the same direction at the same time, and two messages going in opposite directions at the same time, the result is you have quadruplex working, or the method by which four messages are sent upon one wire at the same time, an importation from America where this mode of working was made practical. [Quadruplex working with Birmingham was now shown.] Of course, in absolute telegraph work we have all the morning before us to adjust, or at any rate before business commences; but for illustration in this hall we could only get the wire after seven o'clock. Now, you will notice how we speak to a station, although it is 115 miles away, as though it were in the next room. Space by telegraphy is absolutely annihilated.

You have before your eyes what is taking place every day in England and in America, on a great many circuits. In England we have thirteen of these circuits, and some of them are worked in a curious way. Here [drawing on the board] is West Hartlepool, here is Middlesbrough, here is Leeds, here is London. We have one wire between Leeds and West Hartlepool, another wire between Middlesbrough and Leeds, another wire between Leeds and London. Now that wire works quadruplex between London and Leeds, duplex between Leeds and Middlesbrough, duplex between Leeds and West Hartlepool. West Hartlepool works duplex to London, Middlesbrough works duplex to London, and both those stations can work duplex to London at the same time and on the same wire.

But beautiful as this mode of working is, and greatly as it has increased the capacity of our system, it does not compare in design, in efficiency, or in adaptation to what I am going to bring before you now, viz., Wheatstone's automatic-working system. On this we utilize Morse's alphabet. Here mechanism supplants manual labour. There (on the quadruplex) you saw the clerks working, and the rate of their working was dependent upon the rate at which they could key, and that varies from 20 to 30 words a minute, in fact we may take the average number of words sent by a good telegraphist per minute at, say, 30; but when we replace manual labour by mechanism, we can increase that limit to almost anything, and I will show how we are receiving work upon our wires at the present moment at the rate of from 200 to 250 words per minute. The capacity that automatic

working has given us is indicated very well upon that diagram, Fig. 1, which shows the rate at which messages have increased, and the rate at which the mileage of wire has increased. From 1870 to about 1873 or 1874 the rate of increase of wire and of messages was about the same, but then there was a departure. We commenced to understand automatic working and duplex working; and during the last five or six years we have carried them to such a pitch that while the mileage of wire has increased about 100 per cent., the messages have increased over 230 per cent.; so that by the teachings of experience and by the application of scientific thought, we have succeeded in so increasing the capacity of our wires that they have been able to meet the tremendous increase of

FIG. 1.



POST OFFICE TELEGRAPHS.

business. I will show you how this is done. We have a wire here. We prepare our messages by mechanism, and instead of sending them by hand they are punched on paper. Here is an alphabet punched on paper; it is like the preparation of paper for lace in the Jacquard loom, and this perforated paper will be passed through a transmitter. A clerk can only punch at the rate of 30 to 40 words per minute; the instrument can send this punched paper at the rate of 200 to 250 words per minute, so that the instrument is able to take off the work prepared by five or six clerks. Now I want to show you how the news of this country is transmitted. We have here London [drawing on the black board], Leeds, Newcastle; we have there Edinburgh; we have there Glasgow; we have there Dundee; we have there Aberdeen, and we have there the Institution of Civil Engineers. Now, a strip is punched by several punchers; it is put into the transmitter

at the central station, as you see it there [pointing]. Now the strip is going through the instrument, and at the same moment a similar strip is sending its messages to Leeds, to Newcastle, to Edinburgh, to Glasgow, to Dundee, and to Aberdeen, and every one of those stations, as well as, on other wires, Liverpool, Manchester, Birmingham, Bristol, Newport, Cardiff, Plymouth, Exeter, and in other directions other stations, is at the present moment being filled with exciting news, by means of that apparatus that you see before you, and this is going on at the rate of 200 words a minute; so that we have I cannot tell how many writers, at how many stations, being supplied by this process. We have twenty-eight of these news-circuits at work. And that the process is appreciated, if anything can be appreciated by our press, is evident by the fact that instead of the 5,000 words sent per day that were supplied to the newspapers when the telegraphs of this country were in the hands of private companies, there are 934,154 sent now, and last year there were no less than 340,000,000 words supplied to the press; and still they are not satisfied. In 1871 the number of words delivered in one week was 3,598,000; in 1882 it became 6,557,000! This work is done at an absolute loss. The Government has to pay a considerable subsidy towards providing the newspapers of this country with their daily pabulum of news.

One of the great steps in advance, one of the means by which this tremendous business is done, is this system of automatic working. Five years ago we were only able to transmit 147 messages per mile of wire, now we transmit 256, the ratio of 147 to 256 indicating the rate of improvement in the capacity of our wires. One great improvement that we have introduced is fast-speed repeaters. This is a repeater. It is an exquisite instrument in itself. It is very complicated, but very simple in its working; and the result of the introduction of these instruments is to render the rate of working on long circuits the same as the rate of working on short circuits. We have eighty-one of these repeaters in use. By the insertion of a repeater at Leeds, and another at Edinburgh, we are able to maintain that speed of 200 words a minute to all those stations shown on the board, and the value of this repeater is such that there is no more difficulty in sending at a fast rate (I will not say 200 words a minute, but 100 words a minute), between London and Edinburgh, than there would be in sending between London and Calcutta.

On the Continent efforts have been made by Meyer and Baudot to increase the capacity of wires by the application of another

principle, called multiple working. A unit of time is divided into four or more sections, and each section apportioned to a pair of telegraphists at the two ends of a circuit—one to send, one to receive. Each section of time allows one letter to be sent, so that four messages can be in the act of transmission at the same time, though there are no simultaneous signals, as in the quadruplex apparatus. A gain of speed is obtained with type-printing instruments, but the game is not worth the candle, for the additional apparatus needed is complicated and delicate. Its success has not been marked, though an immense amount of talent and ingenuity has been expended on its development. The exquisite mechanism of the Baudot apparatus was one of the features of the Paris Electrical Exhibition of 1881.

With great grief I pass over notes involving some interesting matter that I cannot possibly bring before you, but which you may have an opportunity of reading some day or other. Although statistics are very dry in themselves, statistics are most interesting as showing the progress made in this country and in the world in telegraphy. Here is a diagram (Fig. 2) that illustrates the growth of telegraphy in this country. We started in the year 1870 with 126,000 messages in a week; we steadily progressed until we came to April, when Easter intervened, and Easter, as you know, rather detracts from business habits, and from sending telegrams, and the result is a considerable dip. We then show another dip at Whitsuntide. Epsom races has a small improvement, and Goodwood probably also; but the declaration of war between France and Germany in July of that year sent up this Alpine peak you see here. So you have the Bank Holidays bringing us down again to the depth of despair. We have omitted 1871 in order not to make the diagram too complicated. In 1872 you will find a great increase. You will find the holidays had the same effect, the races less effect, in the months of July and August a tremendous effect. In August, when everybody is thinking of going away for the holidays, you will find a tremendous spur in every year, and then it comes down to the Christmas holidays again. So you will find in 1876, 1878, 1880, 1882. You will find great jumps and starts produced by wars and rumours of war and holidays. You will find the business of the country progressing by the strides shown there. And why does it progress? I say "as ought not to say it," because the work is so well done. I have been to America, I have been on the Continent of Europe, and I can say this without hesitation, that all these countries have a lesson to learn from us. People are very fond of bringing before us America

as an example. We have taken many lessons from America, but America has been very glad to take us as an example also,

FIG. 2.

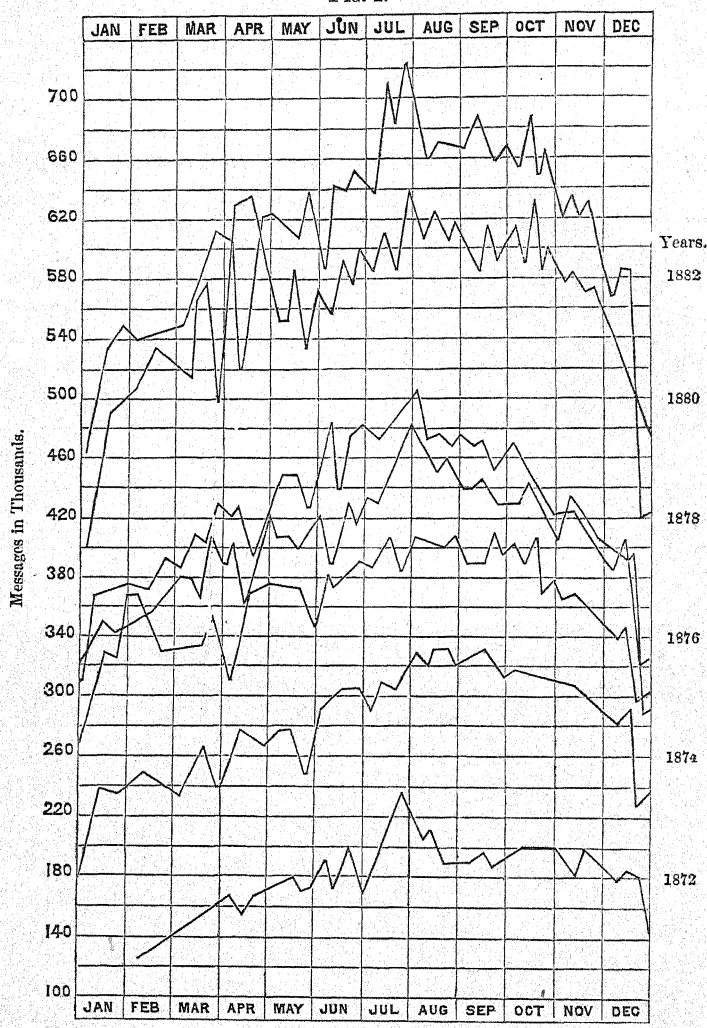


DIAGRAM showing the GROWTH of POSTAL TELEGRAPHY from the day of the Transfer of the Telegraphs to the State to the present date.

and America is now applying on their principal wires in the Western Union system, not only this apparatus, but we have had the pleasure of selecting and sending out experts to show them

how to work this system. We use the telegraph more in England than they do in America, and our tariff is less. In England every hundred persons send 91 messages, while in America they send only 77. We send ten times as much news for the press. The amount of work done in England is indicated by that table, but I can give you a fact interesting in itself. I remember the time when we thought 1,000 messages a day a tremendous business in our central telegraph station. On August 4th, 1882, there were not 1,000 messages sent, but 92,017. Gentlemen, I will not occupy your time by giving you many more figures. The traffic of the Eastern Telegraph Company has increased in equal proportion; in 1871 they sent 186,000 messages; in 1881 they sent 720,000; and the same argument is equally applicable to them—that they have improved their rates of working as we ourselves and other organisations have. The cable companies do an enormous business, and by the way in which they do their business they have revolutionised trade; they have completely altered the mode of transacting business throughout the world; the home trade of this country has been extended to all quarters of the world, and the old middleman is gradually disappearing. In foreign countries, too, we have some remarkable instances of progress in telegraphy. Japan, for instance, last year transmitted no less than 2,223,214 messages, and of these more than 98 per cent. were in their own native tongue; while contiguous China does not possess a single telegraph of its own at the present day, as far as I am aware. There were in 1880, amongst the administrations who had joined the International Bureau of Berne—

Lines of Telegraph	268,000 miles.
Wire	768,600 „
Instruments	53,144

The development of railways in this country has necessitated a corresponding increase in the telegraphs required to ensure the safety of the travelling public, and while 27,000 miles of wire in England, Scotland, and Wales, were used for that purpose in 1869, at the end of December, 1882, the total had increased to 69,000 miles, equipped with 15,702 instruments, against 4,423 in 1869.

Now, gentlemen, my task is done. I have cantered lightly over the ground. I have been very elementary, but I trust I have proved to you that we have not been idle in England. I have said once or twice this week that at 9.45 P.M. on February 15th there will be no happier man in England than your lecturer. I have the satisfaction of knowing that there are some who will

succeed me to undergo the same ordeal, and I trust that when their time arrives to wind up their discourse they will feel as happy as I do now.

Mr. BRUNLEES, President, said he need hardly ask the meeting to give a hearty vote of thanks to Mr. Preece (because he was sure they were all willing to do so) for the very able and interesting lecture to which they had just listened.

The vote was carried by acclamation.

APPENDIX.

I. List of Submarine Cable Companies.

Name.	Mileage of Cable.
	Miles.
Anglo-American	10,688
North American	5,080
Black Sea	350
Brazilian Submarine	3,667
Cuba Submarine	942
Direct Spanish	808
Direct United States	2,983
Eastern	17,082
Eastern and South African	3,858
Eastern Extension	10,430
French Atlantic	3,408
German Union	224
Great Northern	4,850
Indo-European	8
Mediterranean Extension	204
Montevidean and Brazilian	200
Platino Brasileira	1,058
Submarine	609
West India and Panama	4,119
Western and Brazilian	3,750
West Coast of America	5,490
Total	79,808

Railway.	Year ending 31st December, 1869. Mileage of Poles.	Mileage of Wire.	Number of Instruments. Speaking.	Block.	Repeaters and Special Signals.
	Miles.	Miles.			
Brecon and Merthyr	57	119	49	2	..
Caledonian	398	1,120	196	..	45
Cambrian	85	170	25	4	..
Carmarthen and Cardigan	17	34	16	..	..
Cheshire Lines Committee	60	158	23	20	19
Cornwall, South Devon, West Cornwall, and Cornish Mineral	201	531¼	90	169	2
Festiniog	½	½	..	2	..
Furness	93	199	50	22	..
Glasgow, Barrhead and Kilmarnock Joint	6¾	13½	2	..	..
Glasgow and Paisley Joint	Not on own poles	20	2	18	2
Glasgow and South Western	234	345	78	8	2
,, ,, City of Glasgow Union	..	..	..	..	..
Great Eastern (inc. Tilbury & Southend)	798¼	2,666½	310	122	70
Colne Valley	19	38	7	..	..
Great Northern	534½	1,574	165	446	2
Great North of Scotland	283¼	719½	78	56	5
Great Western (proper)	346	948	261	503	410
,, ,, West London Extension	4½	24	18	26	6
,, ,, Bristol and Exeter	132	476	68	98	15
Greenock and Wemyss Bay	10	20	3	..	..
Highland	258½	701½	75	43	..
Lancashire and Yorkshire	422	1,063	319	65	122
London and North Western	1,086¼	3,513	626	511	10
London, Brighton and South Coast	79¾	193½	46	..	1
London, Chatham and Dover	141½	659¼	169	367	..
,, ,, Dover and Deal	(Not open.)				
London and South Western	659	2,010	239	251	44
,, ,, Somerset & Dorset	65	192½	29	44	..
Macclesfield, Bollington and Marple	..	..	..	..	..
Maenclochog	..	..	..	..	..
Manchester, Sheffield and Lincolnshire	265	489	103	..	..
Manchester South Junction & Altrincham	9	43	10	48	24
Maryport and Carlisle	28	56	5	..	..
Metropolitan	10	73½	121	160	91
Midland	1,017	3,248	306	294	374
Mid Wales	48	96	13	18	..
Neath and Brecon	(Line worked by staff and tickets.)				
North British	655	1,366	200	87	13
North Eastern	804¼	2,193¼	282	6	178
North Staffordshire	141½	343½	83	206	..
Oldham, Ashton-under-Lyne & Guide Bdg.	5½	11	3	..	..
Pembroke and Tenby	27½	43	8	..	..
Rhymney	29	107	18	27	7
Severn and Wye and Severn Bridge	(Tramway in 1869.)				
South Eastern	335	1,494	277	626	..
South Wales Mineral	12	13½	3	..	3
Swan Avon Estate and Works Co.	3	3	2	2	..
Swindon, Marlboro' and Andover	(Not open.)				
Taff Vale	50	115	45	2	..
Whitland and Cardigan	(Not open.)				
Total	9,431½	27,203¾	4,423	4,253	1,445

RAILWAY TELEGRAPHS.

Year ending 31st December, 1879.					Year ending 31st December, 1882.				
Mileage of Poles.	Mileage of Wire.	Number of Instruments.			Mileage of Poles.	Mileage of Wire.	Number of Instruments.		
		Speaking.	Block.	Repeaters and Special Signals.			Speaking.	Block.	Repeaters and Special Signals.
Miles.	Miles.				Miles.	Miles.			
61	147	30	43	2	61¼	161½	38	45	10
961	3,252	1,020	920	362	1,002	3,754	1,076	944	470
173	426	66	88	2	173	426	67	90	3
19	38	7	11	..	19	37	5	12	..
105	543	117	330	4	105	594	156	366	15
327	759	154	206	117	329½	775½	161	214	201
13¼	29¼	12	6	2	13¼	30	12	10	..
100½	320¾	83	122	12	107	361¾	93	148	33
29	103	30	36	23	29	103	29	24	30
1¼	33	21	48	54	1¼	36	21	49	58
325	1,062	258	236	54	331	1,122	272	290	89
6	13	3	23	8	6	16	4	29	21
1,062	3,624½	655	643	432	1,142	4,134	805	892	786
Post-office poles	38	7	..	..	(Now maintained by post-office.)				
720	4,190	1,074	2,548	160	855	4,879	1,293	3,250	227
283¾	700½	119	92	..	283¼	690¾	138	108	5
1,549	6,428	1,887	1,807	1,865	1,633½	7,428¼	2,233	2,172	2,338
4½	29	22	26	9	4½	40¼	21	26	14
217	671	144	172	63	218	691	153	184	85
10	22	8	12	4	10	23	10	12	6
400½	1,236¼	147	69	5	402½	1,236¼	147	79	10
582	2,831	491	1,091	915	599	3,081	867	1,217	505
1,840	7,684	1,641	3,015	1,715	1,863	9,125	2,108	4,440	2,351
381½	1,698	609	572	339	430¾	2,037	731	700	425
158	738	222	414	414	159	858	465	563	267
	(Not open.)				8½	25	3	4	..
774	3,670	515	727	835	774	3,730	535	800	1,013
91½	514	54	72	25	91½	514	55	72	25
11	44	9	28	..	11	44	10	28	..
8	24	5	6	..	8	24	6	6	..
296	1,173	367	506	76	313	1,346	415	632	68
19	90	19	78	32	19	88	16	156	20
28	58	13	8	2	39	71	21	8	7
24	201	214	287	204	24	201	214	287	204
1,244	7,871	1,131	3,530	762	1,281	8,350	1,274	3,758	913
48	96	19	24	..	48	96	19	24	..
11¼	11¼	5	4	..	11¼	11¼	5	4	..
765	2,384	409	411	88	1,058	2,826	489	486	8
1,548¼	6,614	923	2,892	2,435	1,578	7,155	989	3,395	3,023
166	431	78	256	70	174	522	139	687	182
5¾	31	17	44	3	5¾	32	17	44	4
27½	55	10	12	..	27½	55	10	12	..
29	107	18	27	7	29	127	19	29	12
25	53	22	28	29	28	61	32	28	29
340	1,618	360	851	147	381¾	1,807½	420	953	189
12	13	4	..	3	12	17	6	..	5
3	3	2	2	..	3	5	2	2	..
	(Not open.)				29	69½	12	21	10
70	189	82	84	29	72	248	84	170	76
14¼	33	5	4	..	14¼	33	5	4	..
14,939¾	61,899½	13,128	22,411	11,308	15,818	69,098½	15,702	27,474	13,737

1 March, 1883.

JAMES BRUNLEES, F.R.S.E., President,
in the Chair.

Telephones.

By Sir FREDERICK BRAMWELL, F.R.S., V.-P. Inst. C.E.

ABOUT forty years ago a clerk of a turnpike trust in the northern part of London, moved thereto no doubt by the sight of Hancock's steam-coach, was provident enough to put upon the notice-board adjoining the toll-gate, "Any carriage driven or drawn by steam, gas, compressed air, or electricity, 1*s*." This far-seeing clerk, had a successor in the Parliamentary draughtsman who prepared the Telegraph Bill of 1869 — a Bill which gave to the Government the monopoly of all telegraphy; for he contrived to use words of so comprehensive a character, that when, eight years afterwards, the telephone was invented, a court of law was compelled to hold that a telephone was a telegraph within the meaning of the Act of 1869. Thus the unborn telephone was in the same relation to the Post Office, as the unborn child of a slave in the old slave days was to the master of its parent—whenever it was born it became a slave. Luckily the lecturer of a fortnight ago—Mr. Preece, the master as representing the Government—is lenient. I tell you all this in order to account for the fact that in these lectures, which are supposed to be given in the chronological order of the invention of their subjects, or in the order of their utilization, you should have for the second lecture on the Applications of Electricity—The Telephone—one of its very latest developments.

Mr. Preece, showed you, in his lecture on "Telegraphy," the means of making certain sounds at a distance—the ringing of a bell, or of two bells of different notes, or the working of the Morse sounder. But the sounds thus produced depended for their character upon the implement at the receiving station, and not upon any sound made at the sending station; indeed there was no necessity for any sound whatever at the sending station, and thus if the bell at the receiving station were changed, the sound

there must also be changed, although precisely the same manipulations as had been previously gone through, might still be carried on at the sending station.

I have spoken of a sending station, and of a receiving station, as though I had full confidence that such terms could not be misunderstood, but even at the risk of your deeming it an excess of precaution, I think it will be well before I go further if I state definitely, that which I intend to convey when I speak of a "transmitter" and of a "receiver." I should not have thought this necessary, had I not found that educated men, unacquainted with telephonic matters, confounded the two terms, and, moreover, were able to defend their want of discrimination. They said, "Why should not the instrument which receives the speech of a speaker be called a 'receiver' and not a 'transmitter,' and why should not the instrument which delivers the reproduction of that speech be called a 'transmitter' and not a 'receiver'?" Such a rendering of the meaning would not be an unreasonable one, and therefore, as I have said, I think it well to state, that when I speak of a transmitter, I mean the instrument which is at the place whence the message is sent, and when I speak of a receiver I mean the instrument which is at the place where the message is received.

Prior to telephonic days you could not only (as Mr. Preece told you) produce sounds at a distance, but in a certain sense you could *re-produce* sounds at a distance. When I say "in a certain sense," I mean that if a note were sounded at the transmitting station that note could be re-produced at a distance. If you were to put a tuning-fork, for example, to work at the transmitting station, and apply it to the break-and-make action employed with an electric current, and then were to place another tuning-fork at the receiving station, a similar note would respond, and in that way persons might be tempted to say you had reproduced the same sound; but that would not of necessity be so: for although the note was the same note, it does not follow that the sound would be the same, because it is obvious that the same "note" may be produced by a tuning-fork, by a violin, by a trumpet, or by a clarionet, but these identical notes would be sounds of very different quality; and prior to telephonic days there were no means of reproducing the *timbre* or quality of the sound; you could reproduce the note, but not the quality. And to my mind, although I am no musician, there is nothing more charming than to listen to a piece of music performed by a full orchestra, and to appreciate the manner in which the different instruments of

wood, brass, and strings contrast or harmonise with each other, as the case may be. For myself I take an ignorant delight in picking out the different sounds, and in observing the wondrous manner in which the skill of the composer has built up, out of these divers sounds, the beautiful whole, that emanated from his mind.

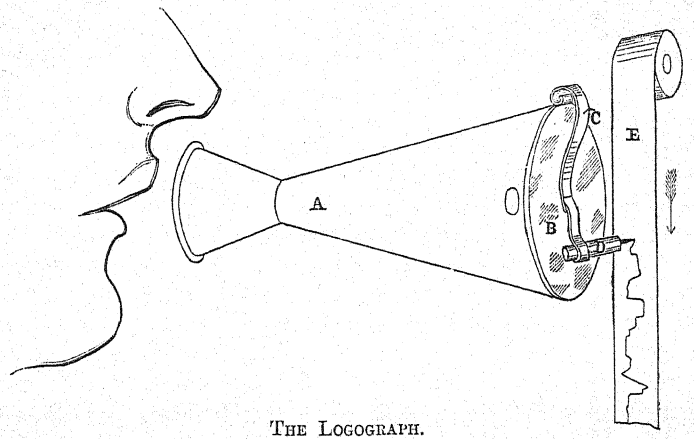
Long prior to the telephone, however, sounds had been reproduced by mechanical connection at short distances. At the old Polytechnic Institution, the Fairy orchestra, the invention of Professor Wheatstone, was an admirable instance of this. I will repeat his experiment before you. We have here a musical box, inside a receiver, and on the top of the box there is a thin wooden board. The box has now been started to play. We will make a vacuum in the receiver, and then I think no one, unless he is quite close, will hear that the box is discoursing music. On passing a rod down through a stuffing-box so as to bring it in contact with the board on the top of the musical box, at the same time placing a guitar on the top of the rod, you will hear the music. There is here obtained the transmission of the sound mechanically, the wooden rod connecting the otherwise inaudible box with the air of this room, that air being acted on by the vibration of the sounding board of the guitar. We have the same thing here on a larger scale. There is a powerful musical box down in the cellar, and from it these long wooden rods have been carried up outside the building, have been passed through two windows, and down, as you see, into the building again. These rods are not so accurately in contact at their connections as I should like them to be, but I think you will be able to hear the guitar if you keep quite silent. In this case the sound is conducted through a much greater length of rod than in the previous instance. But after all, this kind of mechanical connection transmits sounds to but comparatively short distances; and even the string of the toy telephone, of which I shall have to speak hereafter, can only be used over a short distance.

As a preface, and as a step toward the real subject before us this evening, it may be interesting to refer to the Logograph, an invention of our past President, Mr. William Henry Barlow. In Figures 1 and 1*a*, the logograph is represented, and there is given also the reproduction diagramatically of the sounds.

Mr. Barlow argued that the voice, which sets up waves in the air, ought by these waves to be able to set a diaphragm in vibration, and that this vibration ought to be constant for all repetitions of the same syllables and words, and that if those vibrations could

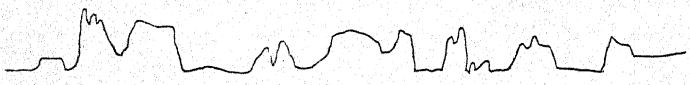
be caused to transmit their character to a travelling band of paper, it would be possible upon looking at the paper, having once learned the characters, to read off at any time that which had been said. Accordingly he made an instrument (see Fig. 1), consisting of a speaking tube A, having a membrane B at one end; on this membrane bore one end of a multiplying lever C, while at the other end of the lever a brush D, in which there was pigment, was fixed, this brush being in contact with the vertically travelling band of paper E, and thus the varying character of the vibrations of the

FIG. 1.



THE LOGOGRAPH.

FIG. 1*a*.



"Each horseman drew his battle blade!"

membrane B are recorded. In Figure 1*a* you have the words "Each horseman drew his battle blade," and above these words is shown the rendering of them by the logograph. This must strike us all as an extremely admirable idea, and had Mr. Barlow succeeded I cannot help thinking that the profession of the gentleman immediately in front of me, the shorthand-writer, would be gone; because all that would then have been needed to obtain a record of speech would have been to employ some person to listen to the speaker, and as he listened to talk to the logograph, and so get the record upon the band of paper. Unhappily I have not the

actual instrument here, but my friend, Mr. Shelford Bidwell, has a means of showing you by a ray of light, the character of the vibrations set up by different vocal sounds. Pending Mr. Bidwell's apparatus being got ready, I may say, Mr. Barlow found that while there were certain syllables the records of which were always the same, whoever spoke, and some the records of which were always the same if the same person spoke, there were others which varied with the different speakers and with different pitches of voice, and so on, and that in fact there was no certainty in the record; thus at present the logograph, while it is a valuable contribution to science, is outside the domain of practical use. We shall see there is much in common in the principle of the logograph and in that of the telephone, and I cannot help thinking that if the logograph and its failure had been known to those who were occupied with telephonic invention, such knowledge would have had a deterrent effect, because it would have led to the belief that a diaphragm acting under the influence of a sound could not be relied upon for behaving in the same manner on a repetition of that sound by a different person. I believe, that when Mr. Graham Bell was engaged in the invention of the telephone, he was not aware of that which Mr. Barlow had done; but I know he has since become acquainted with Mr. Barlow's labours, and has spoken of them in the highest terms.

Mr. Bidwell will now show, upon the screen, a representation of the vibrations produced by certain sounds. *The vibrations produced by the sound O were shown, and the differences between these and those due to the sound of OO, which were also shown, were pointed out.*

We have dealt with the production of similar notes at long distances by the aid of electricity, and we have dealt with the transmission of sounds to short distances by mechanical connections, and we have considered Mr. Barlow's effort to obtain a record of words. We now come to the question, how can speech —not notes, not mere sounds, but actual speech—be reproduced, and at distances, not of feet, nor of yards, but of miles. At such distances as these all hope of a mechanical contrivance must be abandoned; and the investigator would at once turn towards the employment of electricity, a force already in use for telegraphy, and for the production of sound at a distance, and it was in this direction that the inventor of the telephone, Mr. Graham Bell, pursued his investigations.

In thinking out his invention, he set himself this double problem. "I know that speech can cause a disk to vibrate; but knowing that, I have in the first place to learn whether the vibrations can

be made to correspondingly influence electric currents, and if so, I have in the second place to find out if the currents so influenced can be utilized, for the production of vibrations similar to those which had thus generated or controlled these currents?" That was the double problem he set himself.

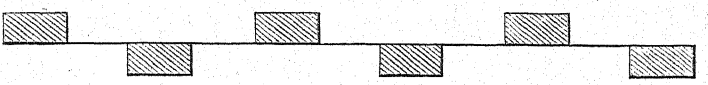
He then investigated what had been done before his time, and he depicted it, so as to have graphically before him, that which had been accomplished. We will now consider his diagrams: if you look at Fig. 2 you will find a line with shaded parts above it, then spaces, then shaded parts, and then spaces. Mr. Bell intended this

FIG. 2.



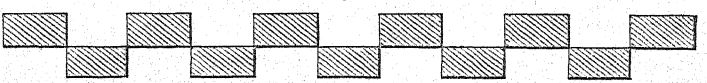
DIRECT INTERMITTENT.

FIG. 2*a*.



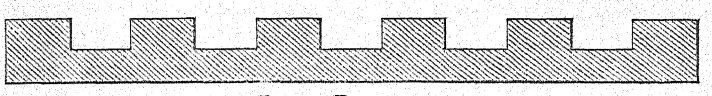
REVERSED INTERMITTENT.

FIG. 2*b*.



REVERSED PULSATORY.

FIG. 2*c*.



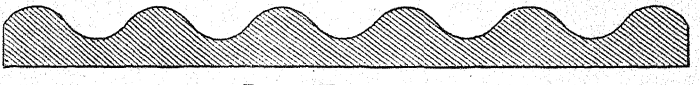
DIRECT PULSATORY.

diagram to represent graphically, first a current, then a cessation of that current, then again a current in the same direction as the first, then a cessation, and so on; and this he called intermittent electricity. In 2*a* you will see that the shaded parts above the line are much wider apart than they were before, and that below the line in the middle of the spaces there are shaded parts corresponding to the parts above. This is intended to represent, first electricity in one direction, then cessation; then electricity in the opposite direction, then cessation; then electricity in the first direction; this Mr. Bell called "reversed intermittent electricity." In 2*b* you will find very nearly the same thing as in 2*a*, except

that the sides of the bottom shaded parts are brought just below the sides of the top ones without any spaces—this is intended to show that a current in one direction is immediately succeeded by a current in the opposite direction. This Mr. Bell calls "pulsatory electricity." In 2*c* you have a line with a shaded height above it at all times; but that height abruptly increasing and abruptly decreasing, representing a continuous current suddenly added to or suddenly deducted from, but nevertheless always a current in one direction; and this Mr. Bell named "direct pulsatory."

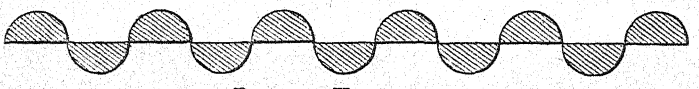
Then Mr. Bell said, "These are the results of "break-and-make," and have been done before; by them can be obtained signals or musical notes, but you cannot get that which I need." I should tell you that in 1862 Mr. Reiss produced, by a break-and-make of this character, that which most nearly approached the telephone

FIG. 3.



DIRECT UNDULATORY.

FIG. 3*a*.



REVERSED UNDULATORY.

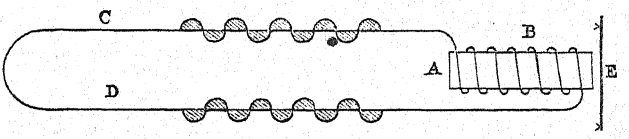
of anything that I know; sounds, and it is said even words, were reproduced by it, but from 1862 to 1876, although telephones were certainly wanted, no one succeeded, or I believe, thought it worth while to try to succeed in making Mr. Reiss' implement into a useful and efficient telephone. These were fourteen dormant years.

Mr. Graham Bell put forward these diagrams in order to show, how it was, that they would not do for the delicate purpose he had in view. Their changes were too abrupt; they were the results of "break-and-make." "What I need," he said, "are circuits that are never broken, and changes that are not abrupt. If I can keep the circuit closed and produce in it an undulatory current, I shall get what I want." Then, in effect, he used these words, "These currents would correspond in rapidity of succession to the vibrations of the inductive plate which generated them, in polarity to the direction of its motion, and in intensity to the amplitude of its vibrations, or rather, to the velocity of its motion." And he

further said, that by means of such currents as these he could impart to the air at the receiving end "a *fac simile* copy" of the motion of the air that had been acting upon the disk at the transmitting end. Mr. Bell then gives four diagrams showing the undulatory currents in closed circuits. Figure 3 represents that which he called "direct undulatory"; that is, where there is always a current flowing in one direction, and where it is added to or deducted from, but these additions or deductions are not made suddenly. 3*a* gives what he calls "reversed undulatory," where, the circuit being always closed, reversals are made, but these reversals are made gradually.

An elementary mode by which Mr. Bell put his ideas into practice is shown by Figure 4. You will see on the right-hand side of the figure a vertical line E, which represents the section of a vibratory disk kept by a frame at a certain distance from a permanent magnet A. Round about that permanent magnet there is wound a coil of insulated wire B, going out along the line C, and returning

FIG. 4.

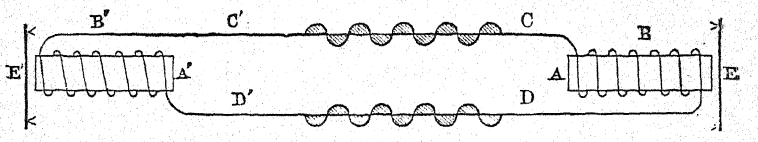


along the line D; and in order to show you the connection between the action of this implement and the previous diagrams, I have repeated upon those wires the reversed undulatory electricity that is to be found shown on Diagram 3*a*. You all know that if an iron plate, a steel plate, or a nickel plate, be caused to approach towards or to recede from a permanent magnet, that magnet being surrounded by a coil of insulated wire, there will be set up in the coil of wire, electric currents, which will vary in direction according as to whether the plate is approaching the magnet or is receding from it. Therefore, we may think of these currents as in one set of circumstances going out by the line C, and coming back over the line D, and in the other set of circumstances as going out by D and coming back by C. Figure 4 shows an apparatus by which it is quite clear that if the disk E be made to vibrate undulatory currents of electricity could be set up, in a closed circuit. Then comes the question. Having got these reversed undulatory currents, how can they be utilized? It is pretty obvious that you can cause them to make another disk, like E, vibrate in the same manner as E vibrated when it generated these currents; in fact,

all that is needed is to repeat the instrument, as we have repeated it in Fig. 5, giving the same letters with a dash added to them, E′, A′, &c., &c., and then, if we pull down the covering piece of the diagram between the two, you will find that the wire goes from the coil B to the coil B′ by C, C′, and back from coil B′ by D′, D, or out by D, D′ and back again by C′, C; and you will see that in this way the power of the magnet A′, and its capability of attracting the disk E′ will be varied, in accordance with the variation in the current produced in the connecting wires by the vibration of the disk E, in front of the magnet A.

It appears to me that, at this very point, a grave doubt ought to have arisen; in fact, a doubt so grave as to have almost deterred any one from pursuing the subject, and, to enable you to go along with me in that doubt, I will now ask Mr. Cottrell, (who has kindly come here from the Royal Institution to help me,) to be good enough to show you an experiment which you have no doubt all seen; but which, nevertheless, it may be well to have

Fig. 5.



fresh in our minds. *Mr. Cottrell then bowed with a double-bass bow the edge of a metallic plate on which sand had been strewed.* You see the forms assumed by the sand upon plates which are put into vibration by the bow of the instrument, and you see, from the beautiful shapes the sand has assumed, that the plate has not been in vibration as a whole; but has been the subject of complex vibrations with nodes between. In Figures 6 and 6*a*, we have a supposititious reproduction not of those particular lines, but of lines upon some other sanded plates.

Looking at these sand forms, I will ask you, would not anybody sitting down to study the matter, be almost forced to say, "It is quite clear that these plates under the influence of sound break up into complex vibrations with nodes between; how, then, if that be the case, can the plate E of Fig. 5, vibrating as a whole in front of the magnet A, do anything more than induce electric currents which will represent a sort of average, as it were, of the true action of the plate?" But if these currents are of a nature indicating only an average, obviously they could only put the disk E′ at the other end in motion in that same average sort of way,

FIG. 6.

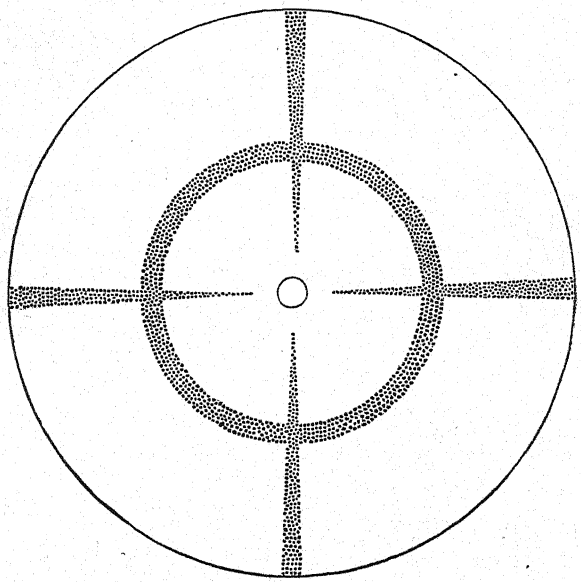
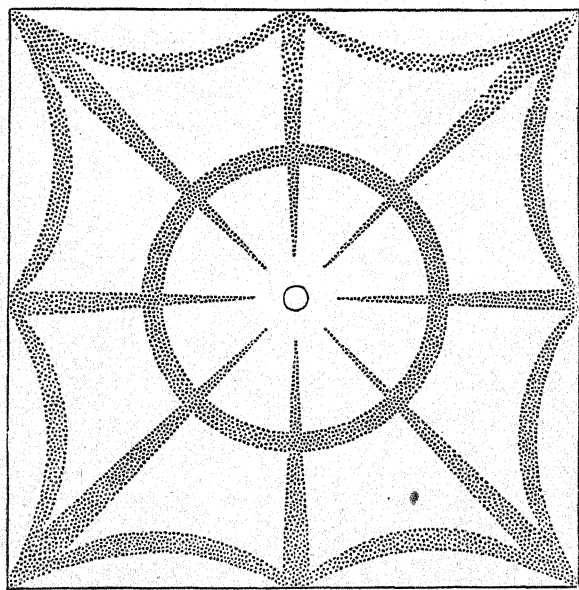
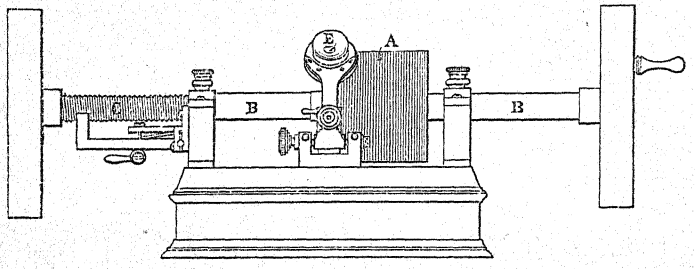


FIG. *Ca*



and equally obviously we could not expect to transmit from the disk E′ to the air in its neighbourhood those complex vibrations which acted upon the first disk E and which it was incapable of communicating to the electric circuit. It seems to me, that any one considering the matter from this point of view, ought to have given up the pursuit as hopeless. Further, would it be taken as credible, that a mere plate of this kind, vibrating all but imperceptibly, should be able to set the air in motion so as to give it an effective sound at all. One is used to the sight of a tuning-fork or of a harp-string vibrating, or to the reed of an accordion in rapid motion, and their vibrations appear to afford an adequate cause for impressing upon the air vibrations sufficient to give forth sound; but this disk vibration, I must say, has always seemed to me insufficient, and this consideration again is enough to tempt any

FIG. 7.



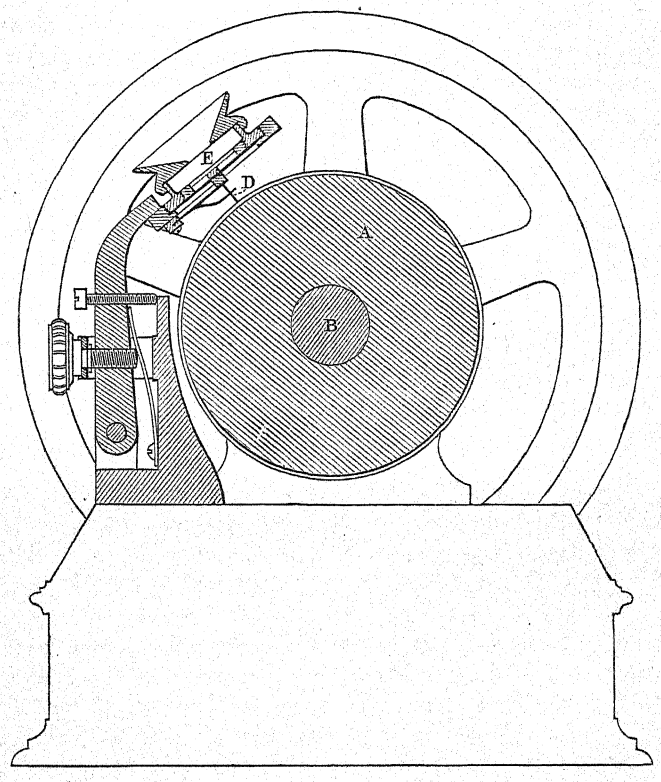
EDISON PHONOGRAPH.

one to give up in despair. But fortunately, Mr. Graham Bell did not give up.

If at the time when Mr. Bell was engaged upon the invention of the telephone, his great—I do not know whether I should call him rival or coadjutor in telephone work,—Mr. Edison,—had invented the phonograph, it would have shown that all these speculations of mine were unnecessary, and that by a mere communication of motion to the centre of a disk, there can be imparted to it these complex vibrations, and that these vibrations, small as they are, are competent to set the air in motion and to reproduce sound. In Fig. 7, we have a longitudinal elevation, and in Fig. 7*a* a cross-section of the Edison phonograph, with which you are all well acquainted. You will see that there is a cylinder A, in which there is cut a spiral, and that this cylinder is now clothed with tinfoil; the cylinder is carried on an axis B, having a screw C at one end, of the same pitch as the spiral, so that

when the cylinder is turned it may also be moved endways, so as to keep the centre of the spiral at all times under a little needle D which comes out from the centre of the disk E that is spoken to, so that the needle may freely indent the foil as it lies over the hollow of the spiral. We have here the instrument itself, and I consider myself extremely fortunate in being favoured

FIG. 7*a*.

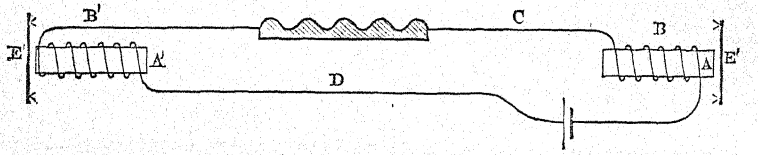


ENLARGED CROSS-SECTION OF PHONOGRAPH.

with the presence of my friend Mr. Johnson, who has helped Mr. Edison in working out many of his inventions. Mr. Johnson has a special power of talking to the phonograph, and I will ask him to say something to the one we have before us. As I have said, I cannot help thinking that if this implement had existed before the invention of the telephone, it would have convinced anybody that a disk when spoken to by a voice, and having a needle at its

centre, is competent to cause that needle to vibrate in such a manner as to be in some way a representation of the complex vibrations of the disk. For what must any one be content to accept as an unassailable proof that the indentations made on the foil are not merely those due to an average movement of that disk, but are in some mysterious way the exponent of the complex vibrations? It seems to me the most exacting doubter must be satisfied with the proof we know the machine affords, for he would find that if the impressed foil be caused to travel under the needle which had impressed it, the needle in being thus moved, and in thereby moving the disk, re-imparts to the disk the very vibrations which the air-waves of speech had originally given to it, and this is proved by the fact that the air set in motion by those vibrations reproduces the speech. *Mr. Johnson here spoke to the phonograph, which repeated that which he had said.* You heard the words which Mr. Johnson said to the phonograph, and under these circumstances you had no doubt about the phonograph's power of repeating

FIG. 8.

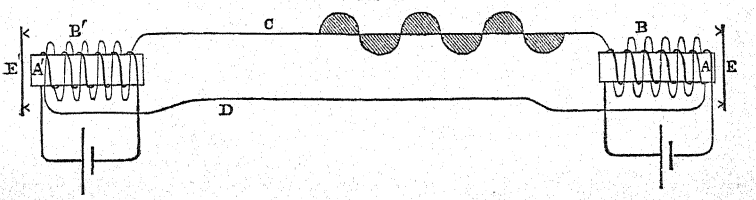


them, but the fact is, although the phonograph in principle is all I have described it to be, the inevitable imperfection attendant upon reducing these principles into practice produces a want of clearness which makes it difficult to catch every word of a sentence uttered by the phonograph if the hearer has not had the benefit of being present when the phonograph was "the talked to" and not "the talker." This defect in detail caused me to abandon a use of the phonograph for this evening to which I had intended to put it. I was in hopes that we might have begun our proceedings to-night by the usual inquiry in the tones of our Secretary, "Is there any gentleman here present for the first time since his election, or who has not signed the register of the Institution?" but I am sorry to say that these words having been spoken to the phonograph, and the Secretary having been called into the room to ascertain whether he recognised the familiar sentence, although he got as far as "Is there any gentleman here to-night," he failed to make out the remaining words, and I had to abandon the experiment, as I felt

it would not do to allow the instrument to give forth sounds which might not be recognised.

Reverting to the Bell telephone you will see that, according to Figs. 4 and 5, we have been considering no battery at all is used, but that each transmitter or receiver (for they act alternately as one or the other) generates its own current by the vibration of the disk. In Fig. 8, however, you will see there is a pair of Bell telephones with a battery in the line-wire; thus acting in the manner suggested by Fig. 3, that is by undulatory electricity. The undulations have been re-drawn on wire C—intended, as before stated, to show that there is always a current flowing from the battery round the coil A, through the line wire C, and back again along D; but that this current is augmented or is diminished by the effect of the vibration of the disk E in front of the core round which the coil is wound. Fig. 9 shows another mode which Mr. Bell uses for carrying out his invention. In this construction two batteries, one at each end, are employed, but these batteries

FIG. 9.



are purely local, the wires of each battery merely making a circuit through the coil round the core, and back to the battery. But outside the primary coil there is a secondary coil, which is in connection with the line wire, and it is the induced electricity set up in these secondary coils which goes along the line wire to do the work. Again I have caused to be drawn on the wire C Mr. Graham Bell's graphic illustration, and in this instance with the induced electricity we have a case of the employment of the closed circuit, and of that which Mr. Bell called you will remember "reversed undulatory." In all three of the foregoing constructions the instruments at the two ends of the line wire are identical in each construction, and are all fit to act both as receivers and as transmitters; and therefore it is perfectly possible to have only one instrument at each end. I have one of them here, and I can use it either as a receiver or as a transmitter. Obviously, however, there is an inconvenience in having only one instrument, because you and your friend at the other end of the line might both be listening when neither was talking, or both might be talking when neither was

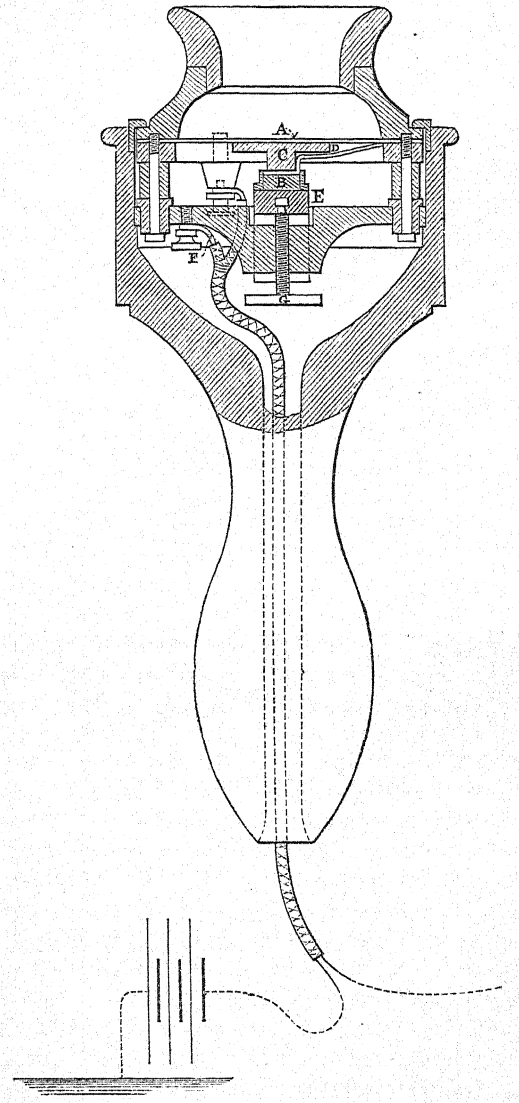
listening. This difficulty is, however, readily conquered by the employment of two instruments at each end of the line.

You will see that in the first mode I showed you where no battery was employed the electricity was generated entirely by the minute vibrations of the inductive plate (the disk) before the poles of the magnet, and even in the second mode where there was a battery in the line wire, or in the third mode where local batteries were used, that which I venture to call the "operative" electricity must be very feeble, for after all it is but produced by the vibrations of these disks. Mr. Bell no doubt saw this, and he also saw another mode of dealing with the operative electricity: which was, to employ a battery to generate the current but to vary the transmitting power of the conductor, and in that manner to vary the current. He, however, only suggested one mode of doing it; this involved a water connection; it turned out it had been suggested before for another purpose; it was found not to be feasible for this, and was given up.

We now come to Mr. Edison, who dealt with the telephone transmitter upon this same principle of varying the power of a conductor, the electricity being provided from an extraneous source. Mr. Edison, like Mr. Bell, looked upon the power of readily varying the conductivity of a liquid connection as a mode by which the desired end might be obtained; but, like Mr. Bell, he discarded it, and set himself to experiment upon other classes of conductors, and he finally selected carbon in some form as the material to be employed. I may say that some years before Mr. Edison's invention Clerac had used carbon (plumbago in powder) for the purpose of varying the conductivity of a circuit. He enclosed it in a tube; he had a screw which pressed upon it, and according to the pressure so was the conducting power. But the screw was set and so remained, unless it was wanted to be set again for another experiment: there was no variation from time to time, and there was nothing to lead up to that which Mr. Edison needed for a telephone, nothing to show the wondrous power of variance of conduction which it is now known is to be found in carbon. Fig. 10 shows one form—an elementary one—of Mr. Edison's carbon transmitter. You will recognise the disk A to be spoken to, but in the case of the Edison transmitter this disk need not be capable of inductive action, in fact it need not be metal at all (mica is suggested, the same material as is used in the phonograph), and that disk has attached to its centre a piece of cork C, which is kept close to a button of carbon B, there being between it and the carbon button a platinum termination D of one of the wires of

a battery; the other side of the carbon button bears against an abutment E, which is in metallic communication with the line

FIG. 10.



EDISON TRANSMITTER.

wire F, and has an adjusting screw G. If now the disk be spoken to, and be thus made to vibrate, it is obvious that the carbon

which is between the disk and the abutment is pressed upon with varying pressure due to the vibration of the disk; but a variation so minute that I should have thought nothing could possibly arise from it, but again I should have been wrong, for from this variation of pressure results the Edison transmitter. It is from the variation in the conductivity of the carbon that the difference in the current which passes from the transmitter to the line wire is obtained, and by this difference we are enabled at the receiving end to make a Bell-receiver speak. With this construction of transmitter the current has no longer to be generated, and even the operative electricity has no longer to be generated by the vibration of the disk, and therefore its motion is not impeded by having this work to do; all that is required of the vibrating disk is simply to vary the power of a current which is generated by a separate battery. In what way this minute variation of pressure upon the carbon operates I do not pretend to tell you. Luckily these are lectures on the application of electricity, not on the science of electricity. The lecturer is not bound to explain the scientific part of the matter unless he pleases, and I most certainly do not please to do it on the present occasion, and for the best of all reasons, I do not know how. Mr. Edison puts forward certain views, but he puts them forward doubtingly; he suggests that it is not so much variation of pressure, as variation in the extent of surface in contact; and those views have also, I believe, been entertained by Professor Hughes, whose beautiful microphone, depending upon the same principle, was exhibited at the Royal Society in 1878.

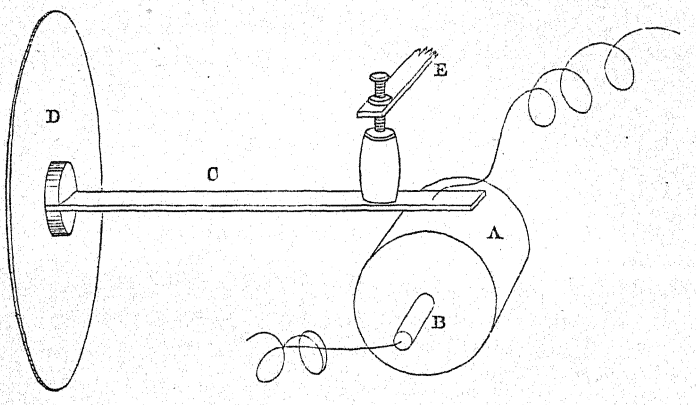
I have endeavoured, for my own information, to find some comparison which should be fairly illustrative of the difference between the mode of action of the Bell transmitter and that of the Edison transmitter, and the one that occurs to me as the most apt is (as is so frequently the case in an illustration of electrical phenomena) based on the hydraulic transmission of power. Suppose in lieu of a line wire there were a water-pipe that led from the transmitter to the receiver, and suppose a small pump were attached to the disk, so that the disk had to work the pump to make impulses of water in the pipe. That I think we might look upon as the condition of a Bell transmitter, whether it generates its own electricity or generates the operative electricity only. If, on the other hand, the pipe were supplied with water from a cistern at an elevation, and there were merely imposed on the disk the work of moving to and fro a throttle valve, so as to make the passage of the water through the pipe more or less easy, that, I think, would be an

illustration of the Edison carbon transmitter. In the one case the disk is charged with the labour of (generating the operative electricity) working the pumps; in the other case it is only charged with the labour of (varying the conducting power) working the throttle valve.

Mr. Edison is not a man to do his work by halves, he therefore did not stop at the transmitter, but set himself to work to invent a receiver. I am glad to say we have two of these instruments here to-night, one of them deriving its needed rotating motion from clockwork, and the other from hand power. Prior to Mr. Edison's time, it had been discovered that the passage of electricity through certain substances varied their friction on bodies moving in contact with them. Notably it was ascertained that the passage of electricity through the human frame varied the friction of substances against the tissues. For instance, it was found that if a patient in an electric bath rubbed his finger along the bath, he perceived that as the current varied, the friction of his finger against the bath differed. Among the bodies, the friction of which is sensibly changed by the variation in the current passing through the surfaces in contact, is chalk, and Mr. Edison availed himself of this in the construction of his chalk receiver, of which we have a diagram on the wall, Fig. 11. This shows a cylinder A of prepared chalk, the spindle of which is connected with the line wire. On the top of the chalk there is a sort of stem C, which is attached to the disk D, and there is a spring E which presses upon the stem with a regulated pressure, and keeps it down upon the chalk; the other wire of the circuit going away from the stem C. If the chalk cylinder be turned in the direction to draw the top of it from the disk, obviously the friction of the cylinder against the underside of the stem will pull the centre of the disk D towards the chalk cylinder, and will pull it to the point where the resilience of the disk is sufficient to prevent it from going further, assuming the friction to remain constant. Under this condition of things it is clear that if the friction could be relieved at all, the disk would go slightly back, while if it could be increased, the disk would be pulled in a little further. I have said that the passage of the electricity through the point of contact between the chalk and the stem will vary the friction, and it does vary it so exactly that, as you speak to the transmitter and thereby vary the current along the line and through the surfaces in contact, the friction varying puts the disk into vibration exactly in accord with the vibration of the disk at the transmitting end, which vibration caused the variation in the electric current. You will see that under these circum-

stances, instead of having to rely upon electricity to work the disk at the receiving end of the telephone line, you rely upon the power put to work the roller; thus there is a new source of power, and all the electricity has to do is to vary the friction. The result is the production of a powerful, loud-speaking receiver competent to be heard all over this large room. I will ask you to look at the different parts as I touch them on the actual instrument I have before me. You see the chalk cylinder, the disk, the stem, and the adjusting spring. I will now ask Mr. Johnson to be good enough to put this instrument into operation by turning the chalk cylinder. Some one is speaking to the transmitter in the basement, and you hear the speech reproduced. We will vary the effect by reproducing a tune from a cornet played in the basement—the tune

FIG. 11.



EDISON'S CHALK RECEIVER.

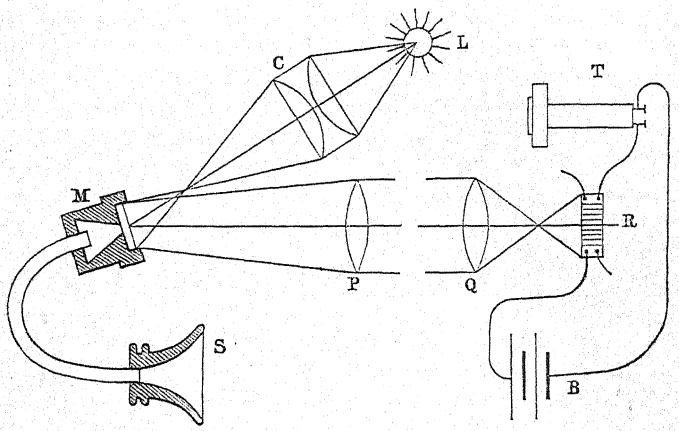
goes on so long as the cylinder is turned, but I will ask Mr. Johnson to be good enough to stop from turning the cylinder, and you observe that although the tune no doubt continues and the electric current continues, the moment he ceases to turn the chalk cylinder, thereby causing a cessation of the effort to draw the stem forward by friction, the sound is cut off. It looks very much as if Mr. Johnson was grinding a barrel-organ and suddenly stopped it, and thereby stopped the production of the tune, but in reality the tune is going on down below: but by cutting off that which in this receiver is the original source of power to move the disk at all—that is, the revolution of the cylinder—you have as effectively cut off the performance as if you had severed the wires themselves, or had directed the performer to cease playing the tune.

I told you that the Bell transmitters were all capable of being used as transmitters and as receivers; Edison's clearly are not. You could not use his carbon transmitter for a receiver; there is no inductive action, nothing to cause the disk to vibrate except the voice, and thus there can be no reverse use of it. Similarly, you could not use the chalk receiver as a transmitter. You might grind the cylinder as much as you please, but I do not think you would succeed in making a variation in the current.

I now come to another most ingenious instrument by Mr. Bell—the Photophone. By the kindness of my friend Mr. Shelford Bidwell we have one here, and I can show you the transmitter portion of it in this room, but the sounds given forth by the receiver are feeble, and could not be heard by more than one or two persons in the audience, and therefore we have the acoustic part of the receiver in the basement: after the lecture those who are prepared to go below will be able to hear the effect. The principle of the Photophone is this. Speech makes a disk vibrate; now, if the disk has a mirror on one side of it those vibrations ought to be recorded by a variation in the light reflected from that mirror. This you have already seen when in the early part of the evening we used this instrument as illustrative of the movement of the diaphragm in the Logograph. The next question is, having got by the aid of speech a varying ray of light, how can that be utilized for the reproduction of that speech. Again the aid of electricity is invoked. There is a material—selenium—which Mr. Willoughby Smith discovered, some years ago, varies in its conducting power according to the amount of light to which it is subjected, and one apparatus that has been used to show this is a selenium eye made by our friend Dr. Siemens. I have it before me, and you see that I am working the eyelids. I ought to have coupled it up to a galvanometer, and then you would have seen that as the light passed through it when the eyelids were open, the galvanometer would stand in one position, and when they were closed, it would vary in its conducting power, and the galvanometer would be in another position. It is by the use of this material, and dependent upon this property of variation in conductive power that Mr. Graham Bell was enabled to construct the photophone, of which Figs. 12 and 12*a* are elementary diagrams. Mr. Graham Bell said: "If I can get these variations of the beam of light, and can cause them to impinge upon selenium arranged in the electric circuit, I ought to be able so to vary the conducting power as once more to put a Bell receiver into action, and to bring forth a repetition of the sounds that were uttered to the disk at the back of the mirror." This

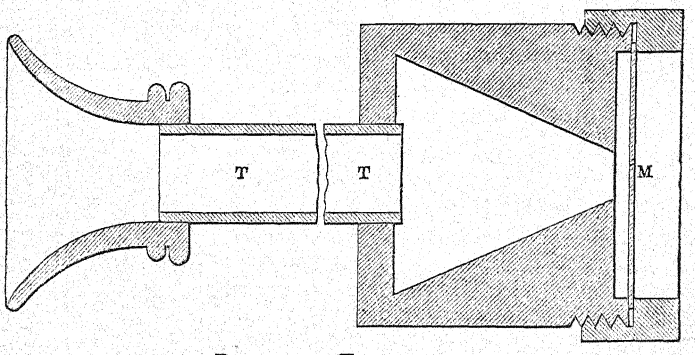
actually takes place, and the line wire no longer remains a necessity for telephonic communication, but the imponderable ray of light may be flashed across a lake, or from mountain top to mountain top, and the otherwise inaudible speech can be reproduced at the very ear of the hearer. I will ask Mr. Cottrell to give us the lime

FIG. 12.



PHOTOPHONE.

FIG. 12*a*.



PHOTOPHONE TRANSMITTER.

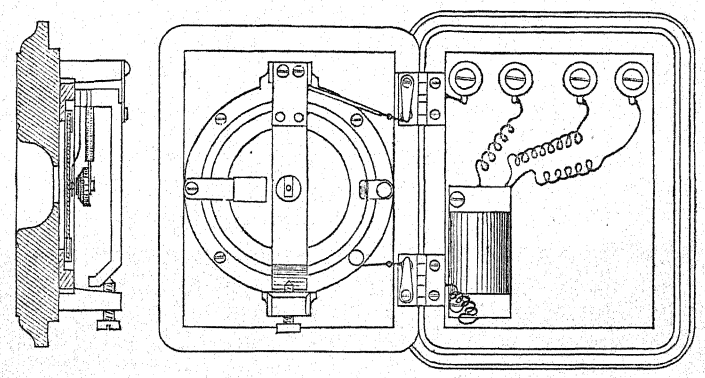
light, and Mr. Shelford Bidwell will be good enough to show you once more upon the screen the appearance presented by the mirror when spoken to.

We will now arrange the photophone with its lenses to direct the rays of light on to the selenium cell at a distance, and when speech

is made to the disk mirror, the variation in light acting on the selenium varies the electric current, and those who are in the quiet down below can hear at the receiver the words that Mr. Bidwell is at this moment uttering to the mirror.

I have now described to you the two kinds of telephones, Professor Graham Bell's and Mr. Edison's. I should think that it is no exaggeration to say that hundreds of modifications have been made upon these primary inventions, but time would utterly fail me if I were to go into them, and I will not do so, except to allude to the receiving instrument of Professor Dolbear. He works by two disks placed very near together, one having a mass of metal at the back, and uses a high charge of electricity which as it varies causes the disk which has not a mass of metal behind it to vibrate in accordance with the variations.

FIG. 13.

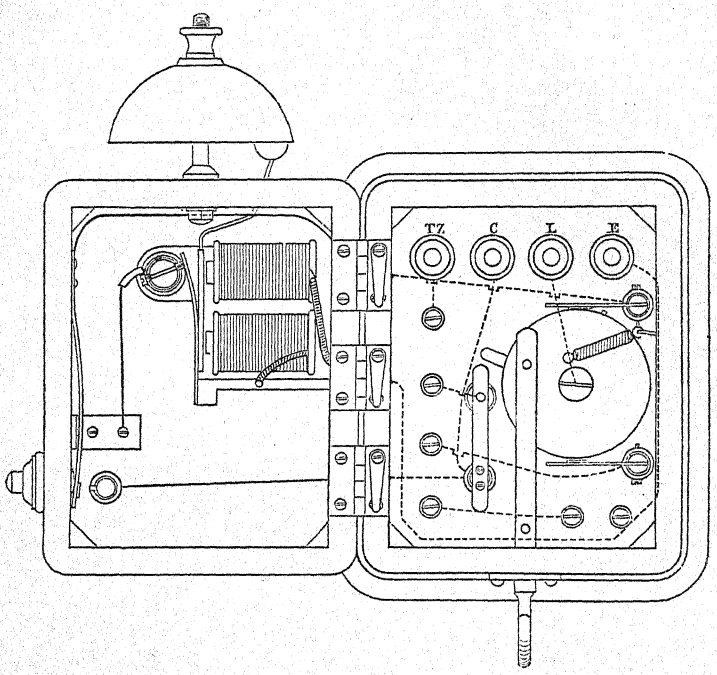


BLAKE TRANSMITTER.

I will now ask you to consider some of the uses of the telephone. First of all there is the very simple case of the private line, with the usual telephonic instruments—the transmitter, the receiver, and the call-bell. This may be the appropriate place to describe the transmitter actually used by the United Telephone Company; it is known as the Blake—one of the modifications of the Edison. I have here such a transmitter, and in the diagram (Fig. 13) you see it represented as thrown open. You will recognise the two battery wires to and from the primary coil, and the secondary coil from which the line wire goes. In Fig. 13*a* is shown the switch for the call-bell, an arrangement by which the whole power of the battery is put upon the bell. At that time the telephone is out of circuit. You press a button, and if it is a private-line wire you

ring a bell at the further end of that line wire, or the person at the other end rings your bell, as the case may be. That state of things lasts as long as the weight of the receiving instrument—see Fig. 13*b*—keeps the switch in a particular position. When the weight is taken off, the bell is cut out, as are all the cells of the battery except one, and thereupon the apparatus is in a condition to be spoken through.

FIG. 13*a*.

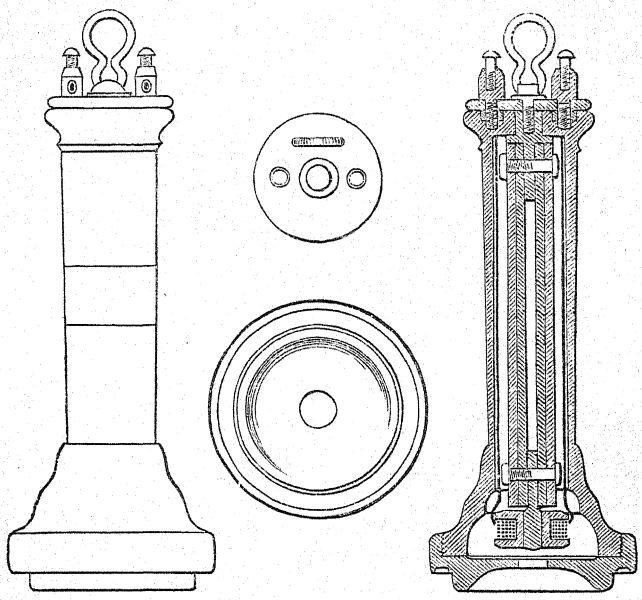


SWITCH FOR CALL-BELL.

The Exchange System is not so simple. The diagram in Fig. 14 is the most elementary of diagrams, showing a supposititious single exchange at E, with a number of subscribers A, B, C, D, and one outlying gentleman who is an unknown quantity X. If A wants to talk to B, all that he has to do is to let the people at the exchange office know he wants to talk to him, and then they couple A to B; so that A and B are as much connected as if there were a private wire from A to B, or as if they were originally on one wire. When A and B have finished their conversation, if A wants to talk to C, B, D, or any one else, the appropriate alterations of connection are made at the exchange. But large

towns cannot be content with a single exchange; they require district exchanges, just as they require district post offices, and then more complex arrangements are necessary such as are shown in Fig. 13. I will ask you to assume that A is the central exchange, and that B, C, D, and the other letters, are district exchanges, while the figures 1, 2, 3, 4, with the letters attached to them, are subscribers whose wires are connected up to these different exchanges. You will see there is a radial connection between the district exchanges and the central exchange, and also very

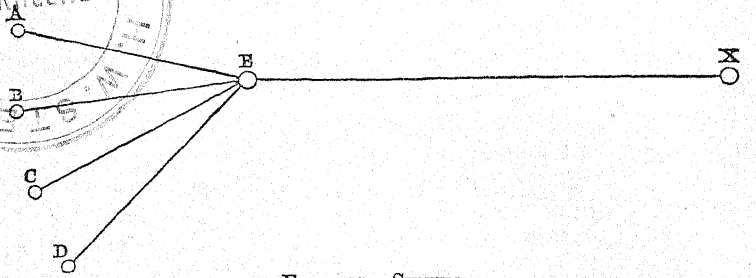
FIG. 13*b*.



frequently a circumferential connection between the district exchanges, and in that way the coupling up may be either from the district station to the central, and back from the central to another district, or may be direct from one district to another, if it be more convenient, and if the line be clear. When the exchange subscriber presses his bell button he clearly cannot ring the bell of the subscriber to whom he may wish to speak, and as a matter of fact he does not ring any bell at all, but operates upon an indicator at his exchange. There is before you a portion of an actual apparatus containing these indicators. It is provided with a series of little shutters, which are ordinarily closed, and thus cover the subscribers' numbers, but if I press the bell-knob of the

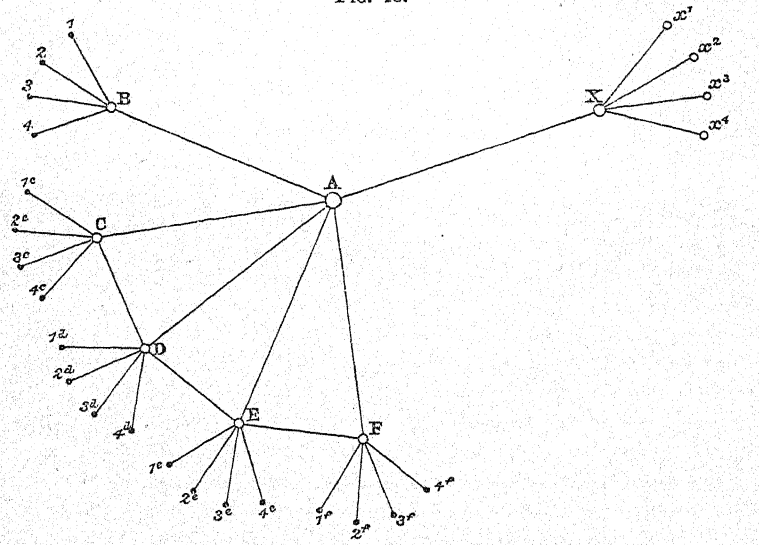
transmitting instrument I have before me, you will see the particular shutter which has been coupled up to this transmitter drop. At the exchange this dropping informs the attendant that number so-and-so desires to speak to another subscriber, whereupon the

FIG. 14.



EXCHANGE SYSTEM.

FIG. 15.



EXCHANGE SYSTEM.

attendant puts into the appropriate hole in a board, such as I have here, which holes bear the same numbers as those covered by the shutters, one of these "jacks," as they are called, and on that he puts another jack, the other end of which connects with the listening table. Having made the connection, the attendant at the

listening table rings a bell, and then speaks through the telephone, asking the subscriber, "What do you want?" "I want number so-and-so." This information being received, the table jack is taken out and the other end of the first jack is put into the other number that is wanted, and the connection is thus made. If the person who is wanted is on another exchange the other exchange is treated as if it were another subscriber, and is by the telephone instructed to couple up to the number called for, and in that way the connection is put through. These calls are made in this country along the line wire, and I believe they are generally so made. But there is one system at work in the United States known as the Law system, where there is a separate wire for the call—not a separate wire for each instrument, but a wire running through a district and taking perhaps ten or fifteen subscribers on the one line of wire. By this wire any one of these subscribers can speak into the telephone exchange directly to an attendant, who perpetually wears a head-dress of receiving instruments—the spring which holds on the head-dress is in fact the permanent magnet—and is therefore always listening to what is taking place. When a subscriber wants anything, he simply calls along the wire, and his want is heard without the necessity of any inquiry, and thus time is saved. Of course you will see there is this difficulty, the one wire being for the sake of economy common to several subscribers, it is possible that when you want to talk to the exchange you may find it is already in use, but even if this be so the waiting is but for a short time. As a matter of fact the Law system seemed to me to work extremely well when I saw it in operation in Philadelphia. I should have liked to call your attention to some specialities of the Newcastle exchange, but the hour at which we have arrived forbids my doing so.

I have described the private line and the exchange systems—the two great commercial uses of the telephone—but there are many entirely special uses. It can be employed as *The Times*, and, for aught I know, other papers employ it to convey intelligence to the compositor, who has a head-dress nearly of the same kind as the one I have described in the Law system, hears what is said to him, and straightway composes it. It has also been used to convey musical performances from theatres, and in doing so the apparatus has been arranged on a principle analogous to that by which a stereoscopic picture is got. By employing telephones on each side of the stage, and by applying the receiver of one of these to one ear, and that of the other to the other ear, the listener is enabled to appreciate the position from which the sound has come,

and to get binaural hearing. I believe that in Paris telephones have been put on the stage itself, and to prevent them from being agitated and thus giving false indications by the vibrations of the floor, they were placed on a very heavy foundation-plate of lead supported upon india-rubber springs, so that although the floor moved, the inertia of the apparatus prevented injurious vibrations being communicated to the telephones.

The use of telephones for fire purposes and for police information of all kinds must be at once obvious. One can imagine also their great value in mining. I will ask you to look at the apparatus by which the telephone is applied to another set of circumstances where as it seems to me it must be all but invaluable. I allude to its use by the diver. Thanks to the kindness of the captain of H.M.S. "Vernon," and of Mr. Gorman, we have here a diver's helmet, in which there is fitted up a transmitting instrument. It only requires that the diver should turn his head a very little on one side to speak directly into it, and he wears close to his ears a pair of receiving instruments. This, while affording a perfect means of communication, has no drawback arising from complications; you will see it involves none; there is only one wire, the sea making the return circuit, and this one wire goes down the ordinary rope that is used as a signal rope, and if the wire breaks, or anything goes wrong with it there are still the same means as there were when there was no telephone. Think of the comfort and of the benefit it must be to a man under such circumstances to be able to give intelligible messages and to receive intelligible answers, instead of being dependent for all communication with the external world upon the one, two, three of the signal line. It is obvious that there must be many other valuable special uses of the telephone, but we have not time to enter into their consideration to-night.

It is certain that the telephone has spread much more rapidly in America than it has here. For example, Washington has a population of about 120,000 white inhabitants, and 60,000 coloured. This population uses eight hundred telephones. Everything in Washington is done by telephone, and the people do not seem to know how to get on without it. I am glad to say, although we do things very slowly here, yet the telephone is at last progressing in England. The United Telephone Company have this day issued a circular, from which it appears that on the 28th of February, 1881, there were connected to the exchange in London (I am leaving out all private wires) 845 persons; on the same day in 1882, 1,505, an increase of 660; and on the same day in 1883, 2,541, an increase of

1,036 in the year. I think it is clear that this rate of increase ought to go on in more than an arithmetical ratio, because the temptation to subscribe must increase with the increase of your speaking power. No one would care to join a telephone exchange if there were only a dozen subscribers to speak to; but when it is found that almost every person with whom you are connected in business has a number in the telephone book, you say, "I also had better belong to it, because I can then be put into instantaneous communication with all these persons." Therefore, as the numbers increase, this very increase must tempt others to join. With the augmented number of subscribers, there comes as a consequence, and all but inevitably, a greater use of the telephone by the individual subscribers. At the present time the average daily calls of each subscriber are 7·59; each call represents two messages, but if it be taken as representing only one, you will find, unless my arithmetic has gone wrong, that a payment of £20 a year represents 2*d.* for each call, or taking the call and answer, the message each way costs 1*d.* The number of calls per subscriber has been steadily growing, and, as I have said, it is obvious that as the subscribers increase the numbers of calls from each subscriber must multiply, because each has more persons to talk to, and the cost per message must be correspondingly reduced.

Going to another point, that of the line wire connection, I have spoken hitherto as though there were always a complete out and home wire circuit, but, as a matter of fact, generally the circuit is made by a wire only one way, and is completed by the earth. But it is to be regretted that economical considerations render this necessary, as the extreme delicacy of the telephone makes it susceptible of great disturbance by induced currents. If the earth be used as part of the circuit, there is a liability to a variety of disturbing causes from earth currents, and if there be a powerful dynamo-machine in the neighbourhood, some very extraordinary results may be got. To show the great delicacy of this instrument, I may mention that when the telephone was quite a novelty, I was listening at one, the wire of which was carried on telegraph-poles, on which there was a wire conveying Morse's signals, and all those Morse signals could be heard in the telephone simply by induction from one wire to the other. If a complete metallic circuit were not too costly, and if the two wires out and home were very close together, or if they were insulated and twisted into a sort of rope, a great deal of this evil effect of induction would be got rid of, and would be got rid of upon a principle that is readily explicable. Suppose

the effect of induction from a neighbouring wire is to add to or deduct from that which is going on in the telephone wire. Think of it as you would of a pair of scales. If you have a pair of scales, and you put 1 lb. in each scale at the same time, or if you take equal weights out of the two at the same time you do not disturb the balance. If, therefore, you have the two wires of the telephone circuit close together and close to the disturbing influence, that influence acts equally on both wires, and it is as though you put 1 lb. in each scale at the same time, or took out 1 lb. at the same time—that is, nothing is done to disturb the balance, and in that way the difficulty is got rid of.

As to the extreme distance through which telephones can be worked, I have a letter that was sent to me from America stating that one of the lines to New Orleans works admirably through 190 miles. Here we are merely beginning to use the instrument, and we do not require these long distances; but as many persons have asked, What is the limit of possibility? I would say that I should think it depends practically on the excellence of the insulation, and on the avoidance of induced currents. What the extreme practicable limit of working may be I don't know, but here, however, we have a statement that 190 miles is dealt with perfectly.

If in 1876 it had been suggested in this room that we should within two years of that time be able to reproduce at a distance not merely sounds but articulate speech, and not merely articulate speech but every trick and accent of the voice of the sender, so that any one listening could say, "That is my friend So-and-so," or "That is a stranger," or "That is a Scotchman," or "That is a Cockney dropping his h's," would you not have scouted such a suggestion as the dream of a visionary. Yet it is but six years ago since the hint of such a thing being possible reached us, and now the apparatus by which it is effected is in common use, and is regarded with as little attention as is paid to an electric bell; but in this age the world is very soon accustomed to marvels; it does not wonder long; anything that comes forward is hardly a nine days' wonder. I believe if to-morrow a man were seen comfortably flying from the Clock Tower over the river and alighting somewhere, without injury, in Westminster Road, he would excite attention, but I also believe that if the performance were repeated day by day for a week, at the end of that time no more attention would be paid to it than if we had been in the habit of seeing men fly ever since we were born. Bearing this in mind that the interest in the telephone had long since died out, and that so much is now known about it, I really felt a certain amount

of shame in knowing that I was to occupy your time in talking of things with which you were so thoroughly familiar, but in excuse I must ask you to remember that the subject of telephones is really not so simple as it now appears to be. One of our most accomplished electricians, a gentleman who is to give the sixth of these lectures, having had the advantage in 1876 of seeing Mr. Graham Bell in America, and having an instrument made by Mr. Bell given to him, brought it to Glasgow, but he could not for the life and soul of him make it work before the British Association. Again in 1877, at the April soirée of the Royal Society, there were a pair of telephones, and the united wisdom of the Society could not make them work. I saw them at the time, and in my conceit said, "Here is another of these things that one hears of, but which, when put to the proof, are discovered to be failures." Perhaps therefore those who arranged these lectures may be pardoned for thinking that one of the evenings should be occupied by a consideration of the application of electricity to telephones. But I must confess that when I found what a slender stock of even comparatively novel things I had to deal with, I feared you would go away saying, "He has not told us a thing we did not know;" and I am still afraid you will do so. Nevertheless, you have honoured me with such close attention throughout, that I will hope I was and am wrong, and will trust that you will look upon this lecture as being one which could not properly be omitted from the series on the application of electricity to industrial purposes of various kinds. It but remains for me now to express my sincere thanks to Mr. Johnson, to Mr. Bidwell, and to Mr. Cottrell, for the aid they have given me, and to Mr. Forrest, who has assisted me throughout, and in his zeal has given up his domain, to be made, for many days past, a concert room, a carpenter's shop, and I know not what besides, but above all does it remain to me to thank you most sincerely for having so attentively listened to me (many of you under the discomfort of being without a seat) for over an hour and a half.

On the motion of the President, a cordial vote of thanks was passed by acclamation to Sir Frederick Bramwell for his highly instructive lecture.

15 March, 1883.

JAMES BRUNLEES, F.R.S.E., President,
in the Chair.

The Electrical Transmission and Storage of Power.

By Dr. C. William Siemens,[1] F.R.S., M. Inst. C.E.

Mr. President, Colleagues, and Gentlemen,—If I interpret rightly the intention of your Council, it was not that these lectures should be what may be called popular lectures, or appeals to mere amateurs interested in the subject; nor do I understand that it was their intention that they should be strictly scientific lectures, such as would deal with ultimate laws, and formulas, or such other information as might be found in text-books; but I presume the intention was that those members of your body who have given thought and study, and also attained experience in particular branches of engineering, should communicate their knowledge to their colleagues, having regard particularly to the younger members of the profession.

The general subject that has been selected for the present session is Electricity—the most subtle of the forces of nature which it is the business of the Civil Engineer, according to the terms of our Charter, to direct. The two lectures preceding this have been devoted to the action of electricity when it is a swift agent, carrying our thoughts to distances only limited by geographical bounds. The first lecture, by Mr. Preece, dealt with telegraphy; the second, by Sir Frederick Bramwell, was upon that branch of telegraphy (for so I must call it)—telephony, which accomplishes the wonderful feat of communicating speech to reasonable distances. In both cases the receiving instrument is of the most delicate nature that the ingenuity of engineers has been able to contrive for recording the small efforts of energy flowing through the wire. The task that has been assigned to me is to introduce electricity to you, still as a precise and swift agent, but as one that can moreover accomplish quantitative effects, rivalling those produced by our steam-engines, by our hydraulic accumulators, and by compressed air. It is with reference to electricity in this form

[1] Dr. Siemens received the honour of Knighthood at the hands of the Queen on the 20th of April following.—Sec. Inst. C.E.

that I propose to put certain experiments and explanations before you.

Electricity, as you know, is the youngest form of energy with which we are practically acquainted. Although the only available source of that energy was until lately the galvanic battery, attempts were made from the days of Volta, at the beginning of the present century, to apply that force for the obtaining and transmitting of power. A very little consideration will convince us that all those efforts must necessarily have been futile. A pound of zinc is produced by the combustion of from 15 to 20 pounds of coal, and while a pound of coal in burning gives out 12,000 heat-units, a pound of zinc in burning gives only 2,340. Thus zinc gives in burning only one-fifth of the effect in energy that coal does, and taking the cost of zinc at 50 times that of coal, it follows that the cost of energy, in the case of a galvanic battery, is, roughly speaking, 250 times greater than in a steam-boiler. Thus handicapped, it was not likely that electricity could be made available for producing powerful effects, although the attempts that were made—in ignorance of the laws of nature governing the force of electricity—were numerous.

Before entering upon the most essential part of my subject, I must mention an invention or discovery of Seebeck in 1822—that of the thermo-battery. I have here a thermo-battery in which the heating agent is gas, which we will have lighted, and you will see that from it proceeds a current, exceedingly weak, yet a current which owes its origin entirely to heat; and by it we can effect transmutation, so to speak, of heat energy into electrical energy, without any intermediate mechanism or contrivance. If alternate strips of metal, of different positions in the thermo-electrical scale, such as bismuth and antimony, are joined at the ends into couples, and one point of juncture is heated, while the next is kept cool, a current is set up, flowing from the hot to the cold juncture, and the moving power of the current thus produced is proportionate to the difference of temperature between the hot juncture and the cold, and to the relative positions of the two metals in the thermo-electric scale. If this transformation could be effected without loss, we might hope that the thermo-battery would be the ultimate and most perfect solution of the problem of developing electric energy out of heat. Sir William Armstrong, in his inaugural address at York in 1881, as President of the Mechanical Section of the British Association, drew particular attention to the thermo-battery, as one of the most hopeful sources of ultimate electrical effect, and physical experimentalists should never lose

sight of this interesting problem. Yet the thermo-battery has one drawback, in common with the steam-engine or any thermo-motor —that is, it is dependent, not only on the first law of thermo-dynamics, according to which heat is changed entirely into its equivalent of electricity, but also on the second law, which says that whenever such conversion of heat takes place, a certain amount of heat must descend from a point of high-potential to a point of low-potential. It is thus that our best steam-engines give in mechanical force only about one-seventh of the theoretical equivalent of the heat-energy; and it is owing to this second law of thermo-dynamics that there must be necessarily a loss of heat, by conduction in the metal strips themselves, which conducted heat must be abstracted at the cooled extremities all round, in order to keep up the extremes of temperature upon which the action of the thermo-battery depends. We will now see whether we can produce a visible effect by the current on the electro-dynamometer, an instrument the nature of which I shall have occasion to describe hereafter. The action is not great, but you see that there is a very decided deflection to this side of about 5 degrees. The battery has not been on long, or it would probably amount to 10 degrees. From measurements which I have only lately made at leisure, I find that it would require one thousand eight hundred single pairs of these strips to produce a potential sufficient to work an incandescent electric light, showing how very slight the current really is.

I now approach a subject in our lecture which is of the greatest importance. I have here the original magnet, and the original coil, which Faraday used in the year 1831—fifty-two years ago—to develop the first induction spark. In 1826, or 1827, he had already conceived the idea that when an armature was removed forcibly from a permanent magnet, the expenditure of force should give rise to a current in the wire surrounding the armature; but it took him three or four years to develop the idea. When Faraday saw the spark, and was able to show it to the members of the Royal Institution, it was a red-letter day in his existence, and he even then thought that it would be a point of departure of some importance, because he said on that occasion: "Although this spark is very small, so that you can hardly perceive it, others will follow who will make this power available for very important purposes." Now that the light is lowered, I will draw your attention to the point of the wire touching this little disk or pan, and you will distinctly observe the spark when I break the connection. This magnet is

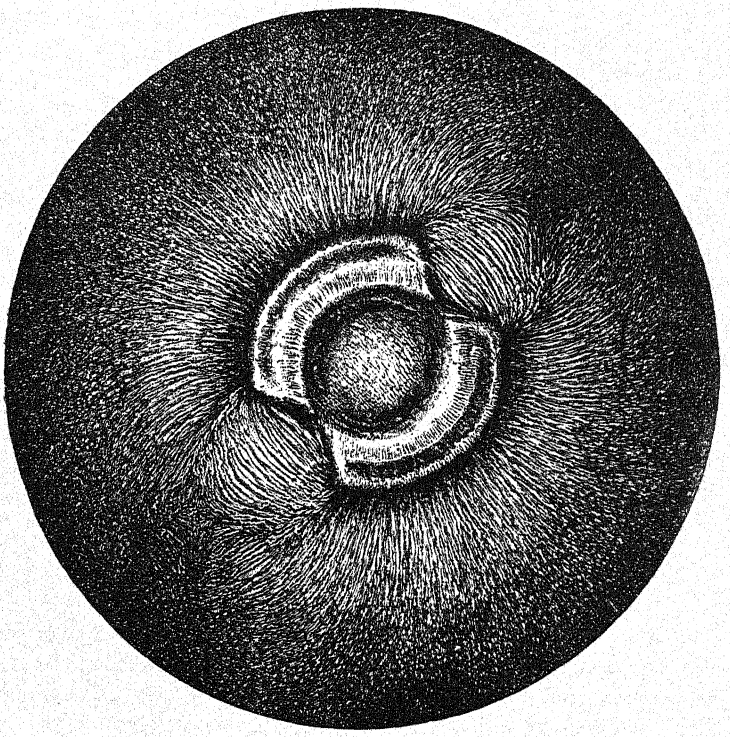
the very steel magnet which Faraday used, and at that time it was quite a giant amongst magnets.

Faraday next turned his attention to magneto-electricity, and to what was called by him the magnetic field. I have here a horse-shoe electro-magnet, with its two stems surrounded by coils of wire. If a current is passed through the coils, these extensions become magnetic poles, and if I lay a piece of cardboard upon them, and spread over it some iron filings, you will observe that, under the influence of the electric current, they distribute themselves in a very peculiar way. Most of the iron filings you see have massed upon two spots, exactly corresponding to the two poles; and all round these spots, lines which are called the lines of magnetic force are shown by the iron filings. It is, of course, difficult, in an experiment of this sort, to show the action as completely as one can in a laboratory; I have accordingly brought some photographed cards, which are certainly very instructive. In these the result of the attraction of the poles, the outflowing lines, as it were, of force from the magnet running in all directions, are well depicted. In the one that has been reproduced, in Fig. 1, the two half-circles, intensely white, are the magnetic fields of a dynamo-machine such as you see before you, and the diagram enables us to trace the intensity and direction of the magnetic action in every part of the machine.

Now if a wire forming a closed circuit was taken across these lines of force, although passing only through air (indeed it might be passing through a vacuum), it would encounter resistance due to the magnetism, and this resistance manifests itself as a current of electricity passing through the wire. I shall endeavour to make the experiment in such a way as to render this action visible to you. I have here my magnetic field, that is to say, two polar surfaces opposed to one another, and a framework wound six times round and round with wire; a single wind would do, but by winding six times I repeat the action which would take place upon the one wire sixfold, and this action I expect will be manifested upon a galvanometer-needle with which this frame is connected. I can move the frame about away from the magnetic field and no action is produced on the needle, but when I move the wires into the magnetic field, there is an action in one direction, and when I move it out again there is an action in the contrary direction. The current produced in this wire is exactly proportionate to the amount of force which I exerted, and this again is proportionate to the rapidity of the motion and to the intensity of the

magnetic field. If the two poles are set very close together, and if the current exciting the electro-magnet is great, the current produced in the induction wires will be great also. Again, if I move the wires through the magnetic field with great velocity I encounter greater resistance, and I shall obtain a still greater result. In fine the mechanical power expended in passing the wires through the magnetic field, is converted at once into electric power or current.

FIG. 1.



SECTION OF DYNAMO MACHINE.

When the magneto-current had been scientifically proved, it was soon taken advantage of in the construction of the machines of Paxii, of Holmes, and of the Alliance Company, which latter machines were made successful at a very early date in lighting some of the coasts of France, and also of this country. Steel magnets were employed, between the poles of which armatures

furnished with coils of insulated wire were made to rotate, when, by the inductive action thus produced, alternating currents were set up in the coils, and conveyed to the electric lamp without being changed into a continuous current by means of a commutator.

The next advance upon Faraday's original conception was an armature by which the inductive action can be multiplied considerably. In the Faraday instrument the armature was separated from the magnet by lifting it away from it. In this, which is generally known as the (Werner) Siemens armature, the coil is put upon an H piece of iron, and made to rotate in a magnetic field. There are in the magneto-machine placed on the table steel magnets superposed one above the other, and between the poles of these magnets such an armature is made to rotate with considerable velocity. You will easily perceive that each time the iron head of the armature is separated from the line of poles of the permanent magnets, *i.e.* each time it makes a half-revolution there is a severance due to each of these magnets. Therefore if there are eight bars, we have on the one side of the electro-magnet the joint effect of eight severances, and on the other side a similar amount of effect. So that for each half-revolution we get the result of sixteen such sparks as that shown in Faraday's experiment, and if this can be repeated at a very rapid rate we may get sixteen sparks perhaps ten times in a second. We will now connect the current, not with the dynamometer, because it would not be so suitable, but with one of these instruments which are generally used for exploding mines, and I will, with your permission, explode a mine. Instead of one we might have ten or twelve mine-exploders in a series. You observe a very powerful instantaneous current resulting from the action of the machine.

A further step in the development of magneto-machines was furnished by Mr. Wilde of Manchester, by substituting for the steel magnets electro-magnets excited by the current from a separate magneto-machine furnished with the Siemens armature. By this arrangement Mr. Wilde was able to realise much more powerful effects than could have been obtained previously.

Another form in which the Faraday or induced current manifests itself is in an induction coil, and this also represents an essential action which we should realise before going any further. In an induction coil one spiral of insulated wire is put within another, both upon an iron centre. When a bar of iron is surrounded, as in this instance, with wire, through which a current is passed, the bar becomes a magnet; and if outside the wire of the primary

coil, as it is called, fine wire is wound, a current is induced in the secondary coil which is of high potential, or tension, according to the number of turns which the wire makes round and round the bar: therefore if a current of very high potential is wanted, very thin wire has to be taken and coiled round a great number of times, whereas if a current of larger quantity and small potential is required, a thicker wire has to be used, having only a small number of turns. If I were to take a thick wire and make the same number of turns, the outer convolutions would be too far away from the magnet to produce energetic action; I am therefore limited by the space at my disposal round this bar of iron in the amount of effect either in quantity or in potential which I can command. I will now ask Mr. Nebel to connect this wire, and you will see that we have here between these points such a potential that a spark similar to a lightning discharge takes place across the gap, about an inch long, between them. This represents, electrically speaking, a very high potential—probably 80,000 volts.

The machines which we have so far considered depend for their action upon the severance of an armature from a permanent magnet. In the year 1865 another principle of action saw the light of day. It was first communicated by my brother, Werner Siemens, to the Berlin Academy; it was also communicated by myself to the Royal Society three weeks later, and when my Paper was read Professor Wheatstone brought the same idea forward. The principle consists in this, that when the current produced by the severance of an armature surrounded by conducting wire from the poles of an electro-magnet, is sent through the coils of the very magnet that produces the magnetism, a kind of regenerator action is set up. There must be a magnetic field to commence the action, and in our first experiments, this initial amount of magnetism was produced by means of a small battery connected with a separate coil on the electro-magnets; we soon found, however, that no such initial excitement was necessary, but that terrestrial magnetism sufficed to induce in the bars of the electro-magnets a magnetic action sufficient to cause a slight current in the coils of the rotary armature, which, in passing through the coils of the field magnets, increased their magnetic tendency; the result was an increased inductive action, and an increased induced current; this again, in passing through the coils of the field magnets, further increased the magnetic intensity, giving rise to increased inductive action, and to a current of increased intensity. The accumulative action thus set up is limited, however, by the point of magnetic

saturation of which a bar of iron is capable. Up to that point the resistance of the rotary armature rapidly increases, thus causing a direct conversion of mechanical into electrical energy. This is the principle upon which dynamo-machines are now generally conceived, and it gives us a power of increase which Faraday foresaw in his original experiment, when he said that the time would come when the primary effect which he showed would be multiplied indefinitely. The machine which I placed before the Royal Society in the year 1865 is now before you; it has done a great deal of useful work since, having been employed at the Telegraph Works at Woolwich to magnetise steel bars to make them permanent magnets; we will set it at work. The machine is now being worked by a current, for the dynamo-machine can serve either as a power-giving machine, or as a power-receiving machine. If you pass a current through these coils, you transform electric into mechanical energy; if, on the other hand, you turn the armature forcibly round at the same speed as before, you produce nearly the same current which was originally taken in driving it.

At the time the dynamo principle was first announced, great interest was expressed in its behalf by my late friend Professor Clerk Maxwell, who saw in the mutual convertibility, by the same piece of mechanism, of mechanical into electrical effect, and *vice versâ*, a great practical proof of the correlation of physical forces. The phrase, attributed to him in popular essays, viz., that one of the greatest discoveries of the present century was the reversibility of the Gramme machine, must however be received with great reserve, considering that the particular machine with which the name of Gramme is associated was not brought out until five years after the dynamo-electric principle of action had been established.

It is a remarkable feature connected with dynamo-electricity that the second law of thermo-dynamics is not involved. Theoretically speaking, a certain amount of mechanical force can be converted entirely into electrical force; and electrical force theoretically speaking can be so converted into dynamical force. Practically speaking, of course, that is not so. There are necessarily losses, and one of these, which is self-evident, is that the current passing through the coils must produce resistance, and electrical resistance, wherever it appears, converts electric energy into heat energy. Again, the iron bars which are magnetised and demagnetised at every half-revolution set up currents in themselves, for it is natural that instead of the current flowing only through the convolutions of the wire, the iron itself being a

metal, some current will be set up in it, and this current so set up produces the effect of heating the iron; it simply circulates round and round, forming as it were electrical eddies which must be productive of heat.

These losses, however, can be diminished almost indefinitely by increasing the size and conductivity of the wires, and as regards the iron, a form of armature has been devised, which is best illustrated in the machine before us—the Gramme machine—the original conception of which is due to Dr. Pacinotti in 1861. This consists in putting the iron, in the form of wire coiled round and round a non-conducting body, which is surrounded in its turn by the insulated copper wire forming the coils of the rotating armature. The iron wires being surrounded by a non-conducting material, electric eddies cannot circulate in the direction in which they would occur, viz., transversely to that of the wires, whereas the magnetic poles induced by the field-magnets are free to advance within the iron wires at the rate of the rotative motion imparted to them.

We have here another armature which is not entirely according to Pacinotti's idea, but involves it—an armature such as is now largely used in dynamo-machines. On a wooden bobbin are wound coils of insulated wire in a direction parallel to its longitudinal axis, according to a plan due to Von Hefner Alteneck. Each coil of wire thus wound is brought successively into metallic connection with one of these laminæ, through which the current produced within the coil in passing through the magnetic field is conveyed by the commutator and its contact brushes, into the wire constituting the outer circuit, and the coils of the field magnets. A succession of currents is thus set up, all flowing in the same direction and constituting in their aggregate a continuous flow. The chief advantage claimed for this arrangement is that the whole of the wire upon the armature, except where it crosses from side to side at the end, is effective; whereas in the Pacinotti ring the copper returns on the inside of the iron ring, so that only one half of its length receives inductive effect in passing through the magnetic field.

Professor Wheatstone in his Paper mentioned a very significant fact. He said: "If I make a cross-connection between the circuit passing round the armature and the field, I get a momentary very powerful effect." This cross-connection really severs the current into two parallel circuits, one portion passing at once out to the electric light or to the place where the electric effect is to be produced, and the other flowing round the bar-magnets and back

again to the machine. If this arrangement is applied to a machine wound for a continuous circuit, it will not produce any useful result, but if it is modified—that is to say, if, as I showed in a Paper before the Royal Society in 1880, the resistance of the wire on the field-magnets is increased a hundred-fold, then we get a machine capable of very sustained action, and this form of shunt dynamo-machine, as it is called, has been since largely adopted in the production of electric light. The greatest uniformity of current is produced, however, in combining the shunt with the old method of winding the field-magnets by furnishing them with two separate coils, the one of low resistance forming part of the outer circuit, and the other of high resistance consisting of thin wire forming a shunt circuit.

There is another form of dynamo-machine which differs essentially from those I have as yet described, viz., the alternate current machine. This differs from Holmes's type, chiefly in the substitution of electro-magnets for permanent magnets, although De Meritens in his ingenious modification of Holmes's machine continues to give the preference to permanent magnets. The modification adopted by my firm consists in substituting mere coils of wire for the armatures, rotating through the magnetic fields produced by electro-magnets which are excited by means of a dynamo-machine of the original type. The principal advantages obtained in suppressing the iron armatures, are, that less weight has to be put into rapid motion, and that less energy is converted into heat by eddies set up within the iron. This machine represents in fact a return to Faraday's original demonstration of the current set up in a conductor passed through a magnetic field, and it is interesting to observe by inspection of Table I., on page 66, that these machines give the highest yield of electrical energy for a given expenditure of mechanical power. This Table contains a considerable amount of practically useful information. The machines marked D in the first column are of the self-exciting type first described; those marked S D (S meaning shunt) are wound in the manner of a parallel circuit as next described, and those marked W are the alternating current machines to which I have just referred. The second column gives the number of incandescent lights which each machine will sustain. That is perhaps of little importance to our present enquiry; but in another column, to which I would draw particular attention, you have the relative effect per lb. of copper wire in the different machines, and the enormous difference in the values shows sufficiently what scope there is for the development of the dynamo-machine. For instance,

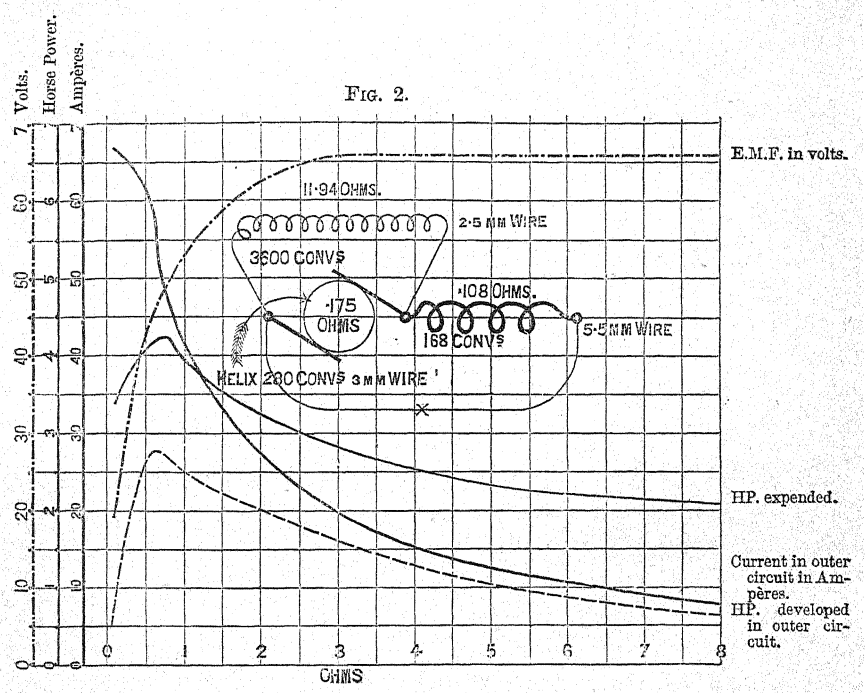
TABLE of PARTICULARS of DYNAMO and ALTERNATE CURRENT MACHINES.

Type of Machine.	Number of Incandescent Lamps of 45 Volts and 1·34 Ampères.	Number of Watts.			Total Number of Watts developed.	Percentage of Total Watts made useful in Outer Circuit.	Total Weight of Copper Wire on Machine in lbs.	Number of Watts in Outer Circuit per lb. of Copper Wire in Machine.	Approximate Circumferential Speed of Helix in Feet.
		In Helix.	In Electro Magnets.	In Outer Circuit.					
'S D 5	12	120	248	796	1,164	68·0	43	18·6	1,900
S D 7	25×2	308	370	3,316	3,994	83·0	113	29·0	2,750
„	40	328	233	2,653	3,214	82·0	141	17·9	2,150
S D 2	30×2	536	319	3,980	4,835	82·0	262	15·1	1,856
„	60	526	326	3,980	4,832	82·0	261	15·2	1,900
S D 1	60×2	803	532	7,959	9,294	85·0	582	13·6	2,050
„	50×3	615	1,200	9,949	11,764	84·5	582	17·0	2,600
D S D 0 0	150×2	2,080	2,562	19,890	24,532	81·7	857	23·1	2,150
B 1	400	1,654	2,666	26,532	30,851	86·0	812	32·5	2,750
W 3	60	193	456	3,979	4,868	81·7	227	17·4	3,650
D 5	..	97	143	..	..	..	..	..	1,550
W 6	90	335	595	5,969	7,240	82·0	312	17·0	4,100
D 6	..	121	220	..	..	..	..	..	1,750
W 2	120	630	633	7,959	9,523	83·5	360	22·1	4,400
D 6	..	107	194	..	..	..	..	..	1,850
W 1	200	1,307	1,257	13,266	16,034	82·7	523	25·3	4,800
D 7	..	110	94	..	..	..	..	..	2,150
W 5	400	1,034	1,496	24,030	26,777	90·0	502	48·0	5,780
D 7	..	117	100	..	..	..	..	..	2,230
W 0	500	1,537	2,375	33,165	37,460	88·0	847	38·9	6,500
D 2	..	177	206	..	..	..	..	..	1,900

in one machine, 1 lb. of copper produces only 17 watts, or units of electric energy; and in another—the last which has been produced—the effect is 48.

[At this point the lecturer was interrupted by a violent report, resulting in the breakage of some glass in the dome of the theatre, which, fortunately, fell outwards, only slight fragments descending into the body of the hall. Windows towards the back of the building were broken, but the Secretary having at once taken steps, and ascertained that the explosion had occurred outside, the lecturer immediately resumed; and it was only after the lecture that it was known that the real cause of the report heard was the explosion of dynamite below the offices of the Local Government Board.]

FIG. 2.

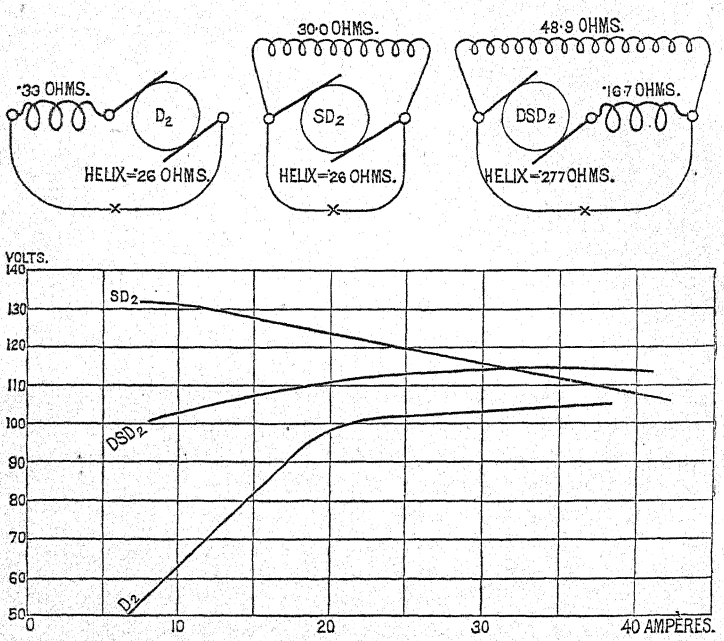


EXPERIMENTS MADE ON THE 21ST OF FEBRUARY, 1880, WITH D_2.

The effect of variation of the resistance of a dynamo-machine is given in Fig. 2. The dash and dot line represents the electromotive force in volts, the complete thin line the horse-power which the machine absorbs, and the dotted line the power developed in the outer circuit, the complete thick line gives the current in the outer circuit in Ampères. You will observe that in proportion as the resistance of the machines increases, both the power expended and power developed diminish, the loss being the difference between these lines. The effect is the height up to the

dotted lines, and it at once becomes evident that the best result is obtained with not quite 1 Ohm resistance. Fig. 3 shows how a dynamo in series differs from a dynamo in shunt. In an ordinary dynamo, the effect increases rapidly with increase of velocity. If the machine were set to work, say with incandescent lights, it will be seen that it would at a low speed give very poor results; but when a certain speed had been obtained, it would be more constant; by the shunt winding, you find, on the contrary, a diminution of effect with increase of speed; whereas in a third

FIG. 3.



E. M. F. CURVES—D_2, SD_2, DSD_2.

(the composite, before described) mode of winding, we can obtain the greatest constancy of effect.

I shall now show you some of the effects that can be produced in transmitting power. In a yard adjoining this Institution a portable steam engine has been erected giving motion to a D 2 dynamo-machine, capable of developing about 8 HP. of electrical energy, or $746 \times 8 = 5968$ Watts. This power is conveyed through an insulated wire to the coils of a D 7 dynamo-machine, the rotating axis of which is practically in one piece with that of a

centrifugal pump, by means of which water can be raised in considerable quantities, and when forced through a nozzle may be lifted 60 feet high. The mechanical effect thus realised amounts to $3\frac{3}{4}$ HP., deduction being made for frictional losses of every kind, and the experiment is interesting as showing a practical application of electric energy to useful purposes. Considering that the weight of the machine is only $3\frac{1}{2}$ cwt., and of the pump about the same (the total being at any rate within half a ton), and that the power could be easily augmented to 5 or 6 HP., I think we may look forward to the time when our fire engines will be worked on this principle.

The Electric Storage Company have been kind enough to send me some of their batteries, and I shall turn their current upon this machine in order to produce the same results as shown before. In this instance the effect, originally produced by the steam-engine, has given motion to a dynamo-machine, the electricity from which has been transferred to the secondary battery, where it has produced chemical action such as I shall presently describe. The store of chemical effect thus produced within the battery is now made available in forming a current, which, passing through the dynamo-machine connected with the pump, imparts motion to the latter. I will now connect the current with a second dynamo-machine to work a saw bench, giving motion at the same time to another dynamo-machine, wound with comparatively thick wire in order to set up a current of very low electrical potential. The potential of the dynamo-machine outside the building is equal to 100 volts, but it is inconvenient sometimes to use a current of such high tension, and my object in transferring the power derived from a machine of high potential to another dynamo-machine wound with thick wire is to obtain a current of low potential, which in this instance does not exceed 10 volts. Such a current could not harm a child, but is most effective where quantity rather than high potential is required, as for instance, for electrolytic purposes. This is what may be called a tertiary machine, and you will observe that it has more effect than either the primary or secondary in heating an iron wire of considerable thickness ($\frac{1}{8}$th of an inch thick), it being what is called a quantitative current. We will now connect the current with a little toy railway, and you will see the result. I may call this a quaternary transmission of force. The steam-engine transferred its energy to a dynamo-machine; this dynamo-machine gave motion to a second, that to a third dynamo-machine, and this again has given motion to the carriage upon the rails, which latter perform

the function of conducting wires. The same power has thus been four times transmitted, showing the great facility with which we can reconvert it again and again from mechanical into electrical, and from electrical into mechanical, effect; and alter its character from a current of high potential to a current of low potential, or *vice versâ*.

I will now allude to an application of electricity lately made by Dr. John Hopkinson, which appears to me to be full of promise. Mr. Nebel will set it to work. It is an electrical hoist. Imagine this to be at the top of a warehouse, and the chain ten times as long as it could be made in this instance, and you will observe that by putting on the current of this dynamo-machine, the weight (which might be much heavier), will be lifted readily, and may be stopped and lowered at will according to the position of the brushes upon the dynamo-commutator.

Another application which has been made with great effect, is that of raising the wire which is used in sounding by Sir William Thomson's wire sounder. On board the "Faraday," the machine has been employed, and the wire is drawn up in an extraordinarily short space of time. We find that by these means we can make a sounding in 2500 fathoms in an hour, because we can go on with the steamer while the electric machine is pulling in the wire. The only drawback which was found in the early trials was that, the machine having been placed near the compasses, the latter were influenced magnetically; the caution, therefore, to be observed, is to put it in a part of the ship away from the compasses.

When losses by unnecessary wire-resistance, by Foucault currents and by induced currents in the rotating armature, are avoided, as much as 90 per cent., or even more, of the power communicated to the machine is realised in the form of electric energy, and *vice versâ* the reconversion of electric into mechanical energy can be accomplished with similarly small loss. Thus, by means of two machines at a moderate distance apart, nearly 80 per cent. of the power imparted to the one machine can be again yielded as mechanical energy by the second, if we leave out of consideration frictional losses, which latter need not be great, considering that a dynamo-machine has only one moving part well balanced, and is acted upon along its entire circumference by propelling force. Jacobi proved, many years ago, that the maximum efficiency of a magneto-electric engine was obtained when

$$\frac{e}{E} = \frac{w}{W} = \frac{1}{2}$$

which law has been construed, by Verdet (Théorie Mechanique de la Chaleur) and others, to mean that one-half is the maximum theoretical efficiency obtainable in electric transmission of power, and that one-half of the current must be necessarily wasted or turned into heat. I could never be reconciled to a law necessitating such a waste of energy, and have maintained, without disputing the accuracy of Jacobi's law, that it has reference really to the condition of maximum work accomplished with a given machine, whereas its efficiency must be governed by the equation

$$\frac{e}{\mathrm{E}} = \frac{w}{\mathrm{W}} = \text{nearly } 1.$$

From this it follows that the maximum yield is obtained when two dynamo-machines (of similar construction) rotate nearly at the same speed, but under these conditions the amount of force transmitted is a minimum. Practically the best condition of working consists in giving to the primary machine such proprotions as to produce a current of the same magnitude, but of 50 per cent. greater electromotive force than the secondary; by adopting such an arrangement, as much as 50 per cent. of the power imparted to the primary could be practically received from the secondary machine at a distance of several miles. Professor Silvanus Thompson, in his recent Cantor Lectures, had shown an ingenious graphical method of proving these important fundamental laws.

The possibility of transmitting power electrically is so obvious that suggestions to that effect have been frequently made since the days of Volta, by Ritchie, Jacobi, Henry, Page, Hjorth and others; but it is only in recent years that such transmission has been rendered practically feasible.

Just six years ago, when delivering my presidential address to the Iron and Steel Institute, I ventured to suggest that "time will probably reveal to us effectual means of carrying power to great distances, but I cannot refrain from alluding to one which is, in my opinion, worthy of consideration, namely, the electrical conductor. Suppose water-power to be employed to give motion to a dynamo-electrical machine, a very powerful electrical current will be the result, which may be carried to a great distance, through a large metallic conductor, and then be made to impart motion to electro-magnetic engines, to ignite the carbon points of electric lamps, or to effect the separation of metals from their combinations. A copper rod 3 inches in diameter would be capable of transmitting 1,000 HP. a distance of say 30 miles, an amount sufficient to supply one quarter of a million candle-power, which

would suffice to illuminate a moderately-sized town." This suggestion was much criticised at the time, when it was still thought that electricity was incapable of being massed so as to deal with many horse-power of effect, and the size of conductor I proposed was also considered wholly inadequate. It will be interesting to test this early calculation by recent experience. Mr. Marcel Deprez has, it is well known, lately succeeded in transmitting as much as 3 HP. to distances up to 40 kilometers (25 miles) through a pair of ordinary telegraph wires of 4 millimetres diameter. The results so obtained were carefully noted by Mr. Tresca, and were communicated a fortnight ago to the French Academy of Sciences. Taking the relative conductivity of the iron wire employed by Deprez, and the 3-inch rod proposed by myself, the amount of power that could be transmitted through the latter would be about 4,000 HP. But Deprez employed a motor-dynamo of 2,000 Volts, and was contented with a yield of 32 per cent. only of the power imparted to the primary machine, whereas I calculated at the time upon an electromotive force of 200 Volts, and upon a return of at least 40 per cent. of the energy imparted. Sir William Thomson at once accepted these suggestions, and with the conceptive ingenuity peculiar to himself, went far beyond me, in showing before the Parliamentary Electric Light Committee of 1879, that through a copper wire of only $\frac{1}{2}$-inch diameter, 21,000 HP. might be conveyed to a distance of 300 miles with a current of an intensity of 80,000 Volts. The time may come when such a current can be dealt with, having a striking distance of about 1·2 foot in air, but then, probably, a very practical law enunciated by Sir William Thomson would be infringed. This is to the effect that electricity is conveyed at the cheapest rate through a conductor, the cost of which is such that the annual interest upon the money expended equals the annual expenditure for lost effect in the conductor in producing the power to be conveyed. It does not appear that Mr. Deprez has considered the effect of this economic law upon his recent experiments.

Sir William Armstrong, in the year 1878, was probably first to take practical advantage of these suggestions in lighting his house at Cragside during night-time, and working his lathe and saw-bench during the day, by power transmitted through a wire from a waterfall nearly a mile distant from his mansion. I have also for some years accomplished the several objects of pumping water, cutting wood, hay, and swedes, of lighting my house, and of carrying on experiments in electro-horticulture from a common centre of steam-power. The results have been most satisfactory;

the whole of the management has been in the hands of a gardener and of labourers, who were without previous knowledge of electricity, and the only repairs that have been found necessary were one renewal of the commutators and an occasional change of metallic contact brushes.

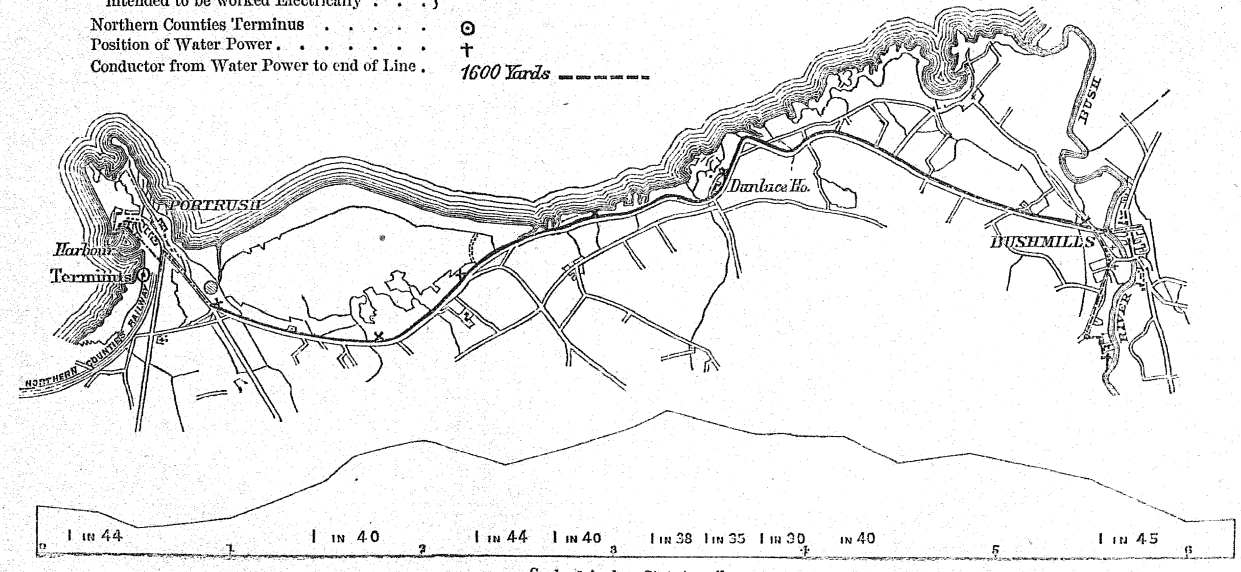
Amongst the numerous other applications of the electrical transmission of power, that to electrical railways, first exhibited by Dr. Werner Siemens at the Berlin Exhibition of 1879, has created more than ordinary public attention. In it the current produced by a dynamo-machine, fixed at a convenient station and driven by a steam-engine or other motor, was conveyed to a dynamo placed upon the moving car, through a central rail supported upon insulating blocks of wood, the two working-rails serving to convey the return current. The line was 900 yards long, of 2-feet gauge, and the moving car served its purpose of carrying twenty visitors through the Exhibition each trip. The success of this experiment soon led to the laying of the Lichterfelde line, in which both rails were placed upon insulating sleepers, so that the one served for the conveyance of the current from the power station to the moving car, and the other for completing the return circuit. This line has a gauge of 3 feet 3 inches, is 2,500 yards in length, and is worked by two dynamo-machines, developing an aggregate current of 9,000 Watts, equal to 12 HP. It has now been in constant operation since the 16th of May, 1881, and has never failed in accomplishing its daily traffic. A line ½ a kilometer in length, but of 4 feet 8½ inches gauge, was established at Paris in connection with the Electric Exhibition of 1881. In this case, two suspended conductors in the form of hollow tubes with a longitudinal slit were adopted, the contact being made by metallic bolts drawn through these slit tubes, and connected with the dynamo-machine on the moving car by copper ropes passing through the roof. On this line 95,000 passengers were conveyed within the short period of seven weeks. The Administration charged 25 centimes (2½*d.*), for the conveyance from end to end of the railway, and the amount was sufficient to pay all expenses. That, therefore, was a case of an electric railway that did pay.

An electric tramway, 6 miles in length, is nearly completed, connecting Portrush with Bush Mills, in the north of Ireland, in the installation of which I have been aided by Mr. Traill, as engineer of the Company, and by Mr. Alexander Siemens, and Dr. E. Hopkinson, representing my firm. In this instance the two rails, 3 feet apart, are not insulated from the ground, but being joined electrically by means of copper staples they form the return

circuit, the current being conveyed to the car through a T iron placed upon short standards, and insulated by means of insulite caps, as shown in plate. Where a gap necessarily occurs such as at a cross road, we simply stop the T-iron and commence it again at the other side of the gap, connecting the two ends by means of an insulated conductor below ground. In order to span this gap we have two brushes attached to the car, one in front and the other towards the back of the car, and the gap being a little less than the distance between the two brushes, the one brush catches the opposite side before the other one leaves. Thus by a simple arrangement we get over the difficulty of crossing bye-roads. For the present the power is produced by a steam-engine at Portrush, giving motion to a shunt-wound dynamo of 15,000 Watts = 20 HP., but arrangements are in progress to utilize a waterfall of ample power near Bush Mills, by means of three turbines of 40 HP. each, now in course of erection. The working-speed of this line is restricted by the Board of Trade to 10 miles an hour, which is readily obtained. With regard to this line, Dr. Edward Hopkinson, who is there, superintending the electrical arrangements, writes to-day, "There is now no difficulty in starting the loaded car on the worst part of the hill, which a steam-engine frequently fails to do." This requires some explanation. You will observe in the plan and sections of the railway given on p. 75, Fig. 4, that there is a long and rather steep incline—1 in 38—two miles in length. There was some doubt in my mind whether, with the arrangements adopted, this incline could be worked satisfactorily; it now appears that it has been, and that the car is drawn up the incline without difficulty when fully loaded. I may, therefore, say that transmission or propulsion by electricity, even under adverse circumstances, is an accomplished fact. A further six miles of extension to Dervock will connect this railway with the railway system of the north of Ireland; we shall then have a length of twelve miles of line of the same gauge, and using the same carriages as those generally used there. Under these circumstances, it seems to me almost a pity that on the Embankment there should be made that series of unsightly and noisome ventilators to disembarrass the underground railway of steam and products of combustion, when it can be clearly demonstrated that electric propulsion would, for the underground railway, not only be the most agreeable, but also the cheapest mode of traction. I shall at any rate, be most happy to afford to engineers every opportunity of studying this question.

FIG. 4.

Portion of Line worked Electrically . . .	5 Miles 330 Yards
Passing Places	×
Steam Engine and Carriage Sheds	⊗
Portion of Tramway in Towns not at present intended to be worked Electrically . . .	·—·—·—·
Northern Counties Terminus	⊙
Position of Water Power	†
Conductor from Water Power to end of Line .	1600 Yards



Scale, 1 inch = Statute mile.

The advantages of electrical propulsion are that the weight of the engine, so destructive of power and of the plant itself in starting and stopping, will be saved, and that perfect immunity from products of combustion will be ensured. The limited experience at Lichterfelde, at Paris, and with another electric line of 765 yards in length, and 2 feet 2 inches gauge, worked in connection with the Zaukerode Colliery since October 1882, are extremely favourable to this mode of propulsion. I, however, do not advocate its prospective application in competition with the locomotive engine for main lines of railway.

For tramways within populous districts the insulated conductor involves a serious difficulty. It will be more advantageous under these circumstances to resort to secondary batteries, forming a store of electrical energy carried under the seats of the car itself, and working a dynamo-machine connected with the moving wheels.

The secondary battery, to which I have already alluded in this lecture, is not an entirely new conception. The hydrogen gas battery suggested by Sir William Grove in 1841, realised in the most perfect manner the conception of storage, only that the power obtained from it was exceedingly slight. In working upon Sir William Grove's idea, twenty-five years ago I constructed a battery of considerable power in substituting porous carbon for platinum, impregnating the same with a precipitate of lead peroxidized by a charging current. At that time little practical importance attached however to the subject, and even when Planté, in 1860, produced his secondary battery, composed of lead plates peroxidized by a charging current, little more than scientific curiosity was excited. It is only since the dynamo-machine has become an accomplished fact, that the importance of this mode of storing energy has become of practical importance, and great credit is due to Faure, to Sellon, and to Volckmar, for putting this valuable addition to practical science into available forms. A question of great interest in connection with the secondary battery has reference to its permanence. A fear has been expressed by many that local action would soon destroy the fabric of which it was composed, and that the active surfaces would become coated with sulphate of lead preventing further action. It has, however, lately been proved in a paper read by Dr. Frankland before the Royal Society, corroborated by simultaneous investigations by Dr. Gladstone and Mr. Tribe, that the action of the secondary battery depends essentially upon the alternative composition and decomposition of sulphate of lead,

which is therefore not an enemy of, but the best friend to, its continued action. The action of the battery depends simply upon the decomposition of the coating of sulphate of lead, so that, commencing with sulphate of lead on both surfaces, this is on the one hand changed into metallic lead, and on the other hand into peroxide; by the action of the battery in producing power it is changed back into its original condition; and there is no *à priori* reason why such a battery should not be available for use for a very long time. Of course you cannot expect to get quite as much of effect out of it as you put in. I am not prepared to say precisely what the loss is, but certainly it is not of such serious import as to prevent the practical use of these secondary batteries. As regards their application to tramways, their usefulness will extend to lines in the interior of towns, and to crossing parts of towns where it would be difficult to establish separate insulated conductors; in such applications the batteries may be charged occasionally by the dynamo on the car in running down hill, or they may be charged in running upon level ground from the dynamo at the power station. In like manner for boat propulsion, the secondary battery is the only available means; because we could never hope to attach a vessel permanently to a rope connected with the shore. The batteries, although heavy, may be made part of the keel-weight; and although neither with the railway nor with the boat should I expect long distances to be traversed with electricity as a motive power, for short distances, and under conditions where steam power is for various reasons not applicable, I believe we have in electric energy an efficient and practicable means of propulsion.

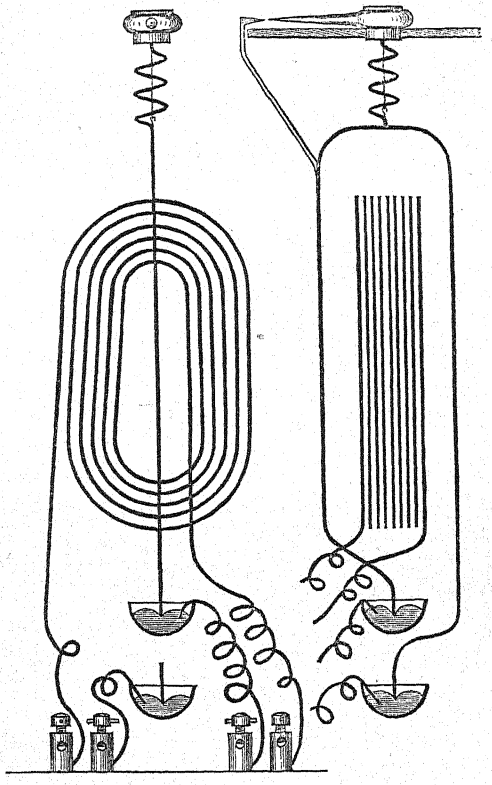
I had intended to say something on the subject of electrical units, and also of the principles involved in measuring currents; but this is a subject which Sir William Thomson will bring before you in a much more complete and exhaustive manner than I can hope to do. I hold, however, in order to know anything about a physical effect, you must be able to measure it, and it is therefore impossible to deal with electric quantities without at the same time looking round at the means at our hand for measuring and weighing, as it were, one effect against the other. The Electric Congress, which met in Paris in 1881, laid down certain general rules, and made certain determinate units for the use of the electrician—the Ohm, the Volt, the Ampère, the Coulomb, and the Farad. But there seemed to be a general want felt for a unit that would give us more directly the amount of work done by a given current; and last summer, in delivering my presidential

address to the British Association, I ventured to propose two additional units—the Joule, representing the unit of heat or of work accomplished by a unit of current in a unit of resistance; and the Watt, the unit of power, or the Ampère flowing through the Volt. This proposal, I am glad to find, has met with very general acceptance. We now measure the power of the dynamo-machine in Watts; and the advantage of this measurement of Volt-Ampères, or Watts, is, that it is the best expression of the power of a machine of given dimensions, which will be capable of producing the same Watt power, either of a high potential and small quantity when thin wire is used on its coils, or of low potential and larger quantity when thick wire is used. Seven hundred and forty-six such Watts are equal to 1 HP.; therefore, if a machine was given to you of say 10,000 Watt power, you would know at once that it would take about 13 HP. to drive it, to which you would have to add 10 per cent. for frictional losses. If we wished to know the effect from that machine, say in working incandescent lights, we may calculate that 3 Watts produce one candle of effect, whereas in the case of a powerful arc light, 1 Watt is capable of producing 3-candle power.

I should have alluded to a number of instruments which have been lent me by the kindness of Professors Ayrton and Perry. They are machines for measuring the different electric quantities, the Volt, the Ampère, and the dynamic effect. I have here, also, an instrument kindly sent me by the Edison Company, which measures the electric quantity in Coulombs. It is based upon the principle of work done chemically. A given current produces an amount of chemical work, and by the amount of chemical work so produced in a branch circuit, the current that has flowed through is estimated. I have already alluded to the dynamometer I usually employ which measures the current in Ampères. This dynamometer consists of one fixed coil surrounded by another coil of a single turn at right angles to the former, through both of which the current passes, so that there will be an attraction between the one wire and the coil of wires, which is proportionate to the square of the current passing; and by the aid of a Table which I have here, I can interpret the deflection produced on the index in Ampères. But we have lately improved upon this in a very simple manner, so as to get the reading at once in Ampère-Volts or Watts. The only difference between the two instruments is, that in the latter case the stationary coil consists of many convolutions, and is of very high resistance, and the single convolution of thick wire, suspended freely, is of very low resistance (see

Fig. 5). Now, when a current flows through a high resistance, we measure its potential, and when through a low resistance, its quantity, hence the mutual attraction between the two is no longer according to the square of the current, but as the energy of the current, and we get Volt-Ampères of current, or Watts.

FIG. 5.



WATT METER.

In conclusion I would only observe that I should have wished to have drawn attention to the various kinds of dynamo-machines which have been developed by different inventors; but it would have been impossible to accomplish this in the space of time allowed me, and moreover I think it better to deal with the principles involved in these machines, than with those most important, yet practical and secondary, results obtained by

modifications of the elements which are at the bottom of all of them. It is so far fortunate that all the essential principles involved in dynamo-machines are public property, and there is a fair field for inventive faculty to develop those forms which are productive of maximum results with the least amount of inconvenience or expense. This is a matter that can only be decided by experience, and little would be gained by upholding one machine to the detriment of another. I hope, at any rate, I have succeeded in giving you a general outline of this most important question of the dynamo-machine and the electric transmission of power.

Mr. BRUNLEES, President, said the lecture just delivered was another manifestation of the active part Dr. Siemens had so beneficially taken for many years in advancing the objects of the Institution, and he was sure all would desire to record the sense of their indebtedness to Dr. Siemens, in the usual manner, by passing a cordial vote of thanks.

The vote was carried by acclamation.

5 April, 1883.

JAMES BRUNLEES, F.R.S.E., President,
in the Chair.

Some Points in Electric Lighting.

By Dr. JOHN HOPKINSON, F.R.S., M. Inst. C.E.

ARTIFICIAL light is generally produced by raising some body to a high temperature. If the temperature of a body be greater than that of surrounding bodies it parts with some of its energy in the form of radiation. Whilst the temperature is low these radiations are not of a kind to which the eye is sensitive; they are exclusively radiations less refrangible and of greater wave-length than red light, and may be called infra red. As the temperature is increased the infra red radiations increase, but presently there are added radiations which the eye perceives as red light. As the temperature is further increased, the red light increases and yellow, green and blue rays are successively thrown off in addition. On pushing the temperature to a still higher point, radiations of a wave-length, shorter even than violet light, are produced, to which the eye is insensitive, but which act strongly on certain chemical substances; these may be called ultra violet rays. It is thus seen that a very hot body in general throws out rays of various wave-lengths, our eyes, it so happens, being only sensitive to certain of these, viz., those not very long and not very short, and that the hotter the body the more of every kind of radiation will it throw out; but the proportion of short waves to long waves becomes vastly greater as the temperature is increased. The problem of the artificial production of light with economy of energy is the same as that of raising some body to such a temperature that it shall give as large a proportion as possible of those rays which the eye happens to be capable of feeling. For practical purposes this temperature is the highest temperature we can produce. Owing to the high temperature at which it remains solid, and to its great emissive power the radiant body used for artificial illumination is nearly always some form of carbon. In the electric current we have an agent whereby we can convert

more energy of other forms into heat in a small space than in any other way; and fortunately carbon is a conductor of electricity as well as a very refractory substance.

The science of lighting by electricity very naturally divides itself into two principal parts—the methods of production of electric currents, and of conversion of the energy of those currents into heat at such a temperature as to be given off in radiations to which our eyes are sensible. There are other subordinate branches of the subject, such as the consideration of the conductors through which the electric energy is transmitted, and the measurement of the quantity of electricity passing and its potential or electric pressure. Although I shall have a word or two to say on the other branches of the subject, I propose to occupy most of the time at my disposal this evening with certain points concerning the conversion of mechanical energy into electrical energy. We know nothing as to what electricity is, and its appeals to our senses are in general less direct than those of the mechanical phenomena of matter. The laws, however, which we know to connect together those phenomena which we call electrical, are essentially mechanical in form, are closely correlated with mechanical laws, and may be most aptly illustrated by mechanical analogues. For example, the terms "potential," "current," and "resistance," with which we are becoming familiar in electricity have close analogues respectively in "head," "rate of flow," and "coefficient of friction" in the hydraulic transmission of power. Exactly as in hydraulics head multiplied by velocity of flow is power measured in foot-pounds per second or in horse-power, so potential multiplied by current is power and is measurable in the same units. The horse-power not being a convenient electrical unit Dr. Siemens has suggested that the electrical unit of power or volt-ampère should be called a watt: 746 watts are equal to one horse-power. Again, just as water flowing in a pipe has inertia and requires an expenditure of work to set it in motion, and is capable of producing disruptive effects if its motion is too suddenly arrested—as, for example, when a plug-tap is suddenly closed in a pipe through which water is flowing rapidly, so a current of electricity in a wire has inertia; to set it moving electromotive force must work for a finite time, and if we attempt to arrest it suddenly by breaking the circuit the electricity forces its way across the interval as a spark. Corresponding to mass and moments of inertia in mechanics we have in electricity coefficients of self-induction. We will now show that an electric circuit behaves as though it had inertia.

The apparatus we shall use is shown diagrammatically in Fig. 1. A current from a Sellon battery A circulates round an electro-magnet B; it can be made and broken at pleasure at C. Connected to the two extremities of the wire on the magnet is a small incandescent lamp D, lent to me by Mr. Crompton, of many times the resistance of the coil. On breaking the circuit, the current in the coil, in virtue of its momentum, forces its way through the lamp, and renders it momentarily incandescent, although all connection with the battery, which in any case would be too feeble to send sufficient current through the lamp, has ceased. Let us try the experiment, make contact, break

FIG. 1.

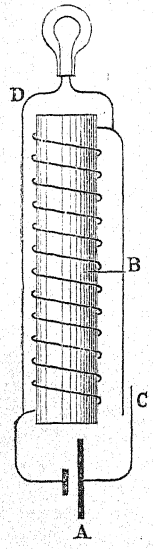
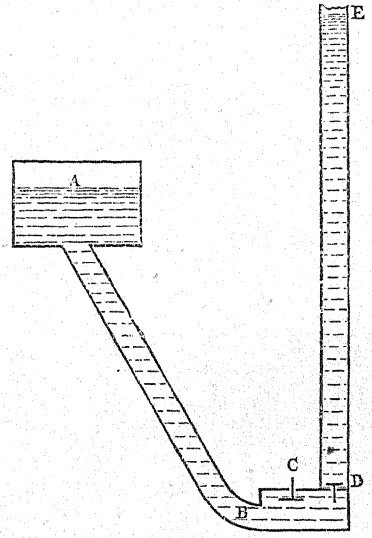


FIG. 2.

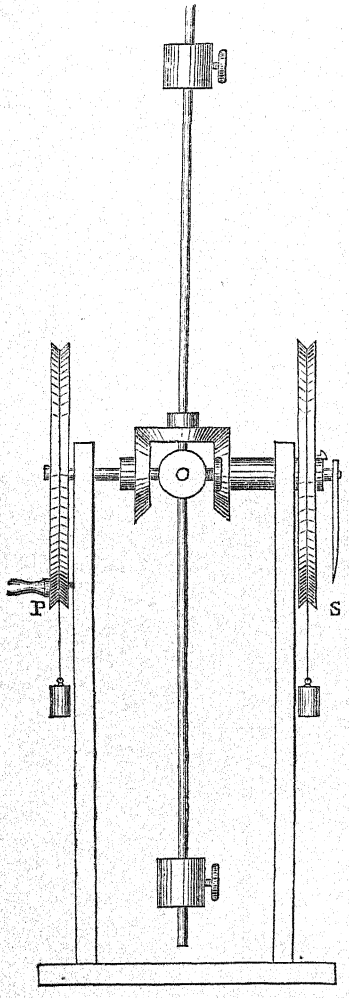


contact. You observe the lamp lights up. Compare with the diagram Fig. 2 of the hydraulic analogue the hydraulic ram. There a current of water suddenly arrested forces a way for a portion of its quantity to a greater height than that from which it fell. A B corresponds to the electro-magnet, the valve C to the contact-breaker, and D E to the lamp. There is, however, this difference between the inertia of water in a pipe and the inertia of an electric current—the inertia of the water is confined to the water, whereas the inertia of the electric current resides in the surrounding medium. Hence arise the phenomena of induction of currents upon currents, and of magnets upon moving conductors—phenomena which have no immediate analogues in

hydraulics. There is thus little difficulty to any one accustomed to the laws of rational mechanics in adapting the expression of those laws to fit electrical phenomena; indeed we may go so far as to say that the part of electrical science with which we have to deal this evening is essentially a branch of mechanics, and as such I shall endeavour to treat it.

This is neither the time nor the place for setting forth the fundamental laws of electricity, but I cannot forbear from showing you a mechanical illustration, or set of mechanical illustrations, of the laws of electrical induction, first discovered by Faraday. I have here a model, Fig. 3, which was made to the instructions of the late Professor Clerk Maxwell, to illustrate the laws of induction. It consists of a pulley P, which I now turn with my hand, and which represents one electric circuit, its motion the current therein. Here is a second pulley S, representing a second electric circuit. These two pulleys are geared together by a simple differential train, such as is sometimes used for a dynamometer. The intermediate wheel of the train, however, is attached to a balanced fly-wheel, the moment of inertia of which can be varied by moving inwards or outwards these four brass weights. The resistances of the two electric circuits are represented by the friction on the pulleys of two strings, the tension of which can be varied by tightening these elastic bands. The differential train, with its fly-wheel, represents the medium, whatever it may be, between the two electric conductors. The mechanical properties of this model are of course

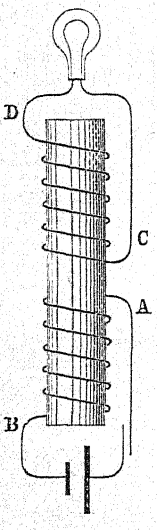
Fig. 3.



obvious enough. Although the mathematical equations which represent the relation between one electric conductor and another in its neighbourhood are the same in form as the mathematical equations which represent the mechanical connection between these two pulleys, it must not be assumed that the magnetic mechanism is completely represented by the model. We shall now see how the model illustrates the action of one electric circuit upon another. You know that Faraday discovered that if you have two closed conductors arranged near to and parallel to each other, and if you cause a current of electricity to begin to flow in the first, there will arise a temporary current in the opposite direction in the second. This pulley, marked P on the diagram, represents the primary circuit, and the pulley marked S on the diagram the secondary circuit. We cause a current to begin to flow in the primary, or turn the pulley P; an opposite current is induced in the secondary circuit, or the pulley S turns in the opposite direction to that in which we began to move the pulley P. The effect is only temporary, resistance speedily stops the current in the secondary circuit, or in the mechanical model friction the rotation of the pulley S. I now gradually stop the motion of P; the pulley S moves in the direction in which P was previously moving, just as Faraday found that the cessation of the primary current induced in the secondary circuit a current in the same direction as that which had existed in the primary. If there were a large number of convolutions or coils in the secondary circuit, but that circuit were not completed, but had an air space interrupting its continuity, an experiment with the well-known Ruhmkorff coil would show you that when the current was *suddenly* made to cease to flow in the primary circuit, so great an electromotive force would be exerted in the secondary circuit that the electricity would leap across the space as a spark. I will now show you what corresponds to a spark with this mechanical model. The secondary pulley S shall be held by passing a thread several times round it. I gradually produce the current in the primary circuit: I will now suddenly stop this primary current: you observe that the electromotive force is sufficient to break the thread. The inductive effects of one electric circuit upon another depend not alone on the dimensions and form of the two circuits, but on the nature of the material between them. For example, if we had two parallel circular coils, their inductive effects would be very considerably enhanced by introducing a bar of iron in their common axis. We can imitate this effect by moving out-

wards or inwards these brass weights. In the experiment I have shown you the weights have been some distance from the axis in order to obtain considerable effect, just as in the Ruhmkorff coil an iron core is introduced within the primary circuit. I will now do what is equivalent to removing the core: I will bring the weights nearer to the axis, so that my fly-wheel shall have less moment of inertia. You observe that the inductive effects are very much less marked than they were before. With the same electromagnet which we used before, but differently arranged, we will show what we have just illustrated—the induction of one circuit on another. Referring to Fig. 4, coil A B corresponds to wheel P; C D to wheel S; and the iron core to the fly-wheel and differential gear. The resistance of a lamp takes the place of the friction of the string on S. As we make and break the circuit you see the effect of the induced current in rendering the lamp incandescent. So far I have been illustrating the phenomena of the induction of one current upon another. I will now show on the model that a current in a single electric circuit has momentum. The secondary wheel shall be firmly held; it shall have no conductivity at all; that is, its electrical effect shall be as though it were not there. I now cause a current to begin to flow in the primary circuit, and it is obvious enough that a certain amount of work must be done to bring it up to a certain speed. The angular velocity of the fly-wheel is half that of the pulley representing the primary circuit. Now suppose that the two pulleys were connected together in such a way that they must have the same angular velocity in the same direction.

FIG. 4.

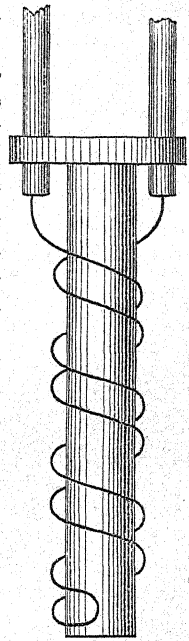


This represents the coil having twice as many convolutions as it had before. A little consideration will show that I must do four times as much work to give the primary pulley the same velocity that it attained before; that is to say, that the coefficient of self-induction of a coil of wire is proportional to the square of the number of convolutions. Again, suppose that these two wheels were so geared together that they must always have equal and opposite velocities, you can see that a very small amount of work must be done in order to give the primary wheel the velocity which we gave to it before. Such an arrangement of the model represents an electric circuit, the coefficient of induction of which is exceedingly small, such as the coils that are wound for standard resist-

ances; the wire is there wound double, and the current returns upon itself, as shown in Fig. 5.

In the widest sense, the dynamo-electric machine may be defined as an apparatus for converting mechanical energy into the energy of electro-static charge, or mechanical power into its equivalent electric current through a conductor. Under this definition would be included the electrophorus and all frictional machines; but the term is used, in a more restricted sense, for those machines which produce electric currents by the motion of conductors in a magnetic field, or by the motion of a magnetic field in the neighbourhood of a conductor. The laws on which the action of such machines is based have been the subject of a series of discoveries. Oersted discovered that an electric current in a conductor exerted force upon a magnet; Ampère that two conductors conveying currents generally exerted a mechanical force upon each other: Faraday discovered—what Helmholtz and Thomson subsequently proved to be the necessary consequence of the mechanical reactions between conductors conveying currents and magnets—that if a closed conductor move in a magnetic field, there will be a current induced in that conductor in one direction, if the number of lines of magnetic force passing through the conductor was increased by the movement; in the other direction if diminished. Now all dynamo-electric machines are based upon Faraday's discovery. Not only so; but however elaborate we may wish to make the analysis of the action of a dynamo-machine, Faraday's way of presenting the phenomena of electro-magnetism to the mind is in general our best point of departure. The dynamo-machine, then, essentially consists of a conductor made to move in a magnetic field. This conductor, with the external circuit, forms a closed circuit in which electric currents are induced as the number of lines of magnetic force passing through the closed circuit varies. Since, then, if the current in a closed circuit be in one direction when the number of lines of force is increasing, and in the opposite direction when they are diminishing, it is clear that the current in each part of such circuit which passes through the magnetic field must be alternating in direction, unless indeed the circuit be such that it is continually cutting more and more lines of force, always in

FIG. 5.



the same direction. Since the current in the wire of the machine is alternating, so also must be the current outside the machine, unless something in the nature of a commutator be employed to reverse the connections of the internal wires in which the current is induced, and of the external circuit. We have then broadly two classes of dynamo-electric machines; the simplest, the alternating-current machine, where no commutator is used; and the continuous-current machine, in which a commutator is used to change the connection of the external circuit just at the moment when the direction of the current would change. The mathematical theory of the alternate-current machine is comparatively simple. To fix ideas, I will ask you to think of the alternate-current Siemens machine, which Dr. Siemens exhibited here three weeks ago. We have there a series of magnetic fields of alternate polarity, and through these fields we have coils of wire moving; these coils constitute what is called the armature; in them are induced the currents which give a useful effect outside the machine. Now, I am not going to trouble you to go through the mathematical equations, simple though they are, by which the following formulæ are obtained:—

$$\mathrm{I} = \mathrm{A} \sin \frac{2\pi t}{\mathrm{T}} \quad \text{(I.)}$$

$$\mathrm{E} = \frac{2\pi \mathrm{A}}{\mathrm{T}} \cos \frac{2\pi t}{\mathrm{T}} \quad \text{(II.)}$$

$$x = \frac{2\pi \mathrm{A}}{\mathrm{T}} \frac{\cos 2\pi \dfrac{t-\tau}{\mathrm{T}}}{\sqrt{\left(\dfrac{2\pi\gamma}{\mathrm{T}}\right)^2 + \mathrm{R}^2}} \quad \text{(III.)}$$

$$\mathrm{Tan} \frac{2\pi\tau}{\mathrm{T}} = \frac{2\pi\gamma}{\mathrm{R\,T}} \quad \text{(IV.)}$$

$$\Theta\, \mathrm{R} \frac{2\pi^2 \mathrm{A}^2}{\mathrm{T}^2} \frac{\mathrm{I}}{\left(\dfrac{2\pi\gamma}{\mathrm{T}}\right)^2 + \mathrm{R}^2} \quad \text{(V.)}$$

$$\mathrm{R} = \frac{2\pi\gamma}{\mathrm{T}} \quad \text{(VI.)}$$

T represents the periodic time of the machine; that is, in the case of a Siemens machine having eight magnets on each side of the armature: T represents the time of one-fourth of a revolution. I represents the number of lines of force embraced by the coils of the armature at the time t. I must be a periodic function of t, in the simplest form represented by Equation I.

Equation II. gives E the electromotive force acting at time t upon the circuit. Having given the electromotive force acting at any time, it would appear at first sight that we had nothing to do but to divide that electromotive force by the resistance R of the whole circuit, to obtain the current flowing at that time. But if we were to do so we should be landed in error, for the conducting circuit has other properties besides resistance. I pointed out to you that it had a property of momentum represented by its coefficient of self-induction called γ in the formula; and when we are dealing with rapid changes of current, it plays as important a part as the resistance. Formula III. gives the current x, flowing at any time, and you will observe that it shows two things: first, the maximum current is less than it would be if there were no self-induction; secondly, it attains its maximum at a later time. This retardation is represented by the letter τ, and its amount is determined by the Formula IV. At a given speed of rotation, the amount of electrical work developed in the machine in any time Θ is given by Formula V. It is greatest when $R = \frac{2\pi\gamma}{T}$. From these formulæ we see that the current is diminished either by increasing γ or increasing R; also the moment of reversal of current is not co-incident with the moment of reversal of electromotive force, but occurs later, by an amount depending on the relative magnitudes of γ and R. They show us that although by doubling the velocity of the machine we really double the electromotive force at any time, we do not double the current passing, nor the work done by the machine; but we may see that if we double the velocity of the machine, we may work through double the external resistance, and still obtain the same current. In what precedes, it has been assumed that the copper wires are the only conducting bodies moving in the magnetic field. In many cases the moving wire-coils of these machines have iron cores, the iron being in some cases solid, in others more or less divided. It is found that if such machines are run on open circuit, that is, so that no current circulates in the armatures; the iron becomes hot, very much hotter, than when the circuit of the copper wire is closed. In some cases this phenomenon is so marked that the machine actually takes more to drive it, when the machine is on open circuit, than when it is short-circuited. The explanation is that on open circuit currents are induced in the iron cores, but that when the copper coils are closed, the current in them diminishes by induction the current in the iron. The effect of currents in the iron cores is not alone to waste energy and

heat the machine; but for a given intensity of field and speed of revolution, the external current produced is diminished. The cure of the evil is to subdivide the moving iron as much as possible, in directions perpendicular to those in which the current tends to circulate.

There remains one point of great practical interest in connection with alternate-current machines, How will they behave when two or more are coupled together, to aid each other in doing the same work? With galvanic batteries, we know very well how to couple them, either in parallel circuit or in series, so that they shall aid, and not oppose, the effects of each other; but with alternate current machines, independently driven, it is not quite obvious what the result will be, for the polarity of each machine is constantly changing. Will two machines, coupled together, run independently of each other, or will one control the movement of the other in such wise that they settle down to conspire to produce the same effect, or will it be into mutual opposition? It is obvious that a great deal turns upon the answer to this question, for in the general distribution of electric light, it will be desirable to be able to supply the system of conductors from which the consumers draw by separate machines, which can be thrown in and out at pleasure. Now I know it is a common impression that alternate-current machines cannot be worked together, and that it is almost a necessity to have one enormous machine to supply all the consumers drawing from one system of conductors. Let us see how the matter stands. Consider two machines independently driven, so as to have approximately the same periodic time and the same electromotive force. If these two machines are to be worked together, they may be connected in one of two ways; they may be in parallel circuit with regard to the external conductor, as shown by the full line in Fig. 6, that is, their currents may be added algebraically and sent to the external circuit, or they may be coupled in series, as shown by the dotted line, that is, the whole current may pass successively through the two machines, and the electromotive force of the two machines may be added, instead of their currents. The latter case is simpler. Let us consider it first. I am going to show that if you couple two such alternate current machines in series, they will so control each other's phase as to nullify each other, and that you will get no effect from them; and, as a corollary from that, I am going to show that if you couple them in parallel circuit, they will work perfectly well together, and the currents they produce will be added; in fact, that you cannot drive alternate-current machines tandem,

but that you may drive them as a pair, or, indeed, any number abreast. In diagram, Fig. 7, the horizontal line of abscissæ represents the time advancing from left to right; the full curves represent the electromotive forces of the two machines not supposed to be in the same phase. We want to see whether they will tend to get into the same phase or to get into opposite phases. Now, if the machines are coupled in series, the resultant electromotive force on the circuit will be the sum of the electromotive forces of the two machines. This resultant electromotive force is represented by the broken curve III; by what we have already seen in Formula IV., the phase of the current must lag behind the phase of the elec-

FIG. 6.

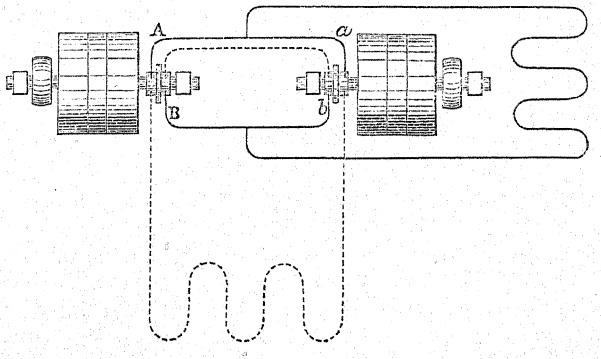
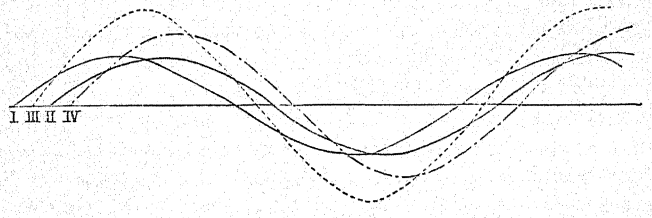


FIG. 7.



tromotive force, as is shown in the diagram by curve IV, thus —·—·—·—. Now, the work done in any machine is represented by the sum of the products of the currents and of the electromotive forces, and it is clear that as the phase of the current is more near to the phase of the lagging machine II than to that of the leading machine I, the lagging machine must do more work in producing electricity than the leading machine; consequently its velocity will be retarded, and its retardation will go on until the two machines settle down into exactly opposite phases, when no current will pass. The moral, therefore, is, do not attempt to couple two independently

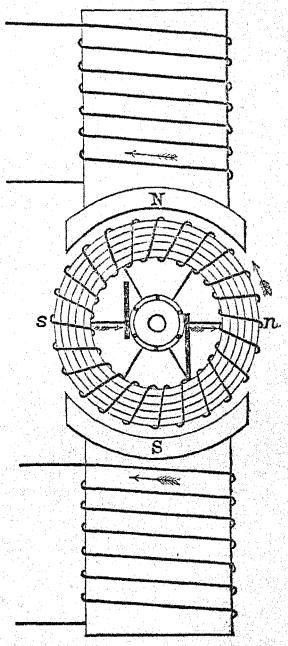
driven alternate-current machines in series. Now for the corollary, A B, Fig. 6, represent the two terminals of an alternate-current machine; *a b* the two terminals of another machine independently driven. A and *a* are connected together, and B and *b*. So regarded, the two machines are in series, and we have just proved that they will exactly oppose each other's effects, that is, when A is positive, *a* will be positive also; when A is negative, *a* is also negative. Now, connecting A and *a* through the comparatively high resistance of the external circuit with B and *b*, the current passing through that circuit will not much disturb, if at all, the relations of the two machines. Hence, when A is positive, *a* will be positive, and when A is negative, *a* will be negative also; precisely the condition required that the two machines may work together to send a current into the external circuit. You may, therefore, with confidence, attempt to run alternate-current machines in parallel circuit for the purpose of producing any external effect. I might easily show that the same applies to a larger number: hence, there is no more difficulty in feeding a system of conductors from a number of alternate-current machines, than there is in feeding it from a number of continuous-current machines. A little care only is required that the machine shall be thrown in when it has attained something like its proper velocity. A further corollary is that alternate currents with alternate current machines as motors may theoretically be used for the transmission of power.[1]

It is easy to see that, by introducing a commutator revolving with the armature, in an alternate-current machine, and so arranged as to reverse the connection between the armature and the external circuit just at the time when the current would reverse, it is possible to obtain a current constant always in direction; but such a current would be far from constant in intensity, and would certainly not accomplish all the results that are obtained in modern continuous-current machines. This irregularity may, however, be reduced to any extent by multiplying the wires of the armature, giving each its own connection to the outer circuit, and so placing them that the electromotive force attains a maximum successively in the several coils. A practically uniform electric current was first commercially produced with the ring armature of Pacinotti, as perfected by Gramme. The Gramme

[1] Of course in applying these conclusions it is necessary to remember that the machines only *tend* to control each other, and that the control of the motive power may be predominant, and *compel* the two or more machines to run at different speeds.

machine is represented diagrammatically in Fig. 8. The armature consists of an anchor ring of iron wire, the strands more or less insulated from each other. Round this anchor ring is wound a continuous endless coil of copper wire; the armature moves in a magnetic field, produced by permanent or electro-magnets with diametrically opposite poles, marked N and S. The lines of magnetic force may be regarded as passing into the ring from N, dividing, passing round the ring and across to S. Thus the coils of wire, both near to N and near to S, are cutting through a very strong magnetic field; consequently there will be an intense inductive action; the inductive action of the coils near N being equal and opposite to the inductive action of the coils near S, it results that there will be strong positive and negative electric potential at the extremities of a diameter perpendicular to the line N S. The electromotive force produced is made use of to produce a current external to the machine thus, the endless coil of the armature is divided into any number of sections, in the diagram into six for convenience, usually into sixty or eighty, and the junction of each pair of sections is connected by a wire to a plate of the commutator fixed upon the shaft which carries the armature; collecting brushes make contact with the commutator as shown in the diagram. If the external resistance were enormously high, so that very little current, or none at all passed through the armature, the greatest difference of potential between the two brushes would be found when they made contact at points at right angles to the line between the magnets; but when a current passes in the armature, this current causes a disturbing effect upon the magnetic field. Every time the contact of the brushes changes from one contact-plate to the next, the current in a section of the copper coil is reversed, and this reversal has an inductive effect upon all the other coils of the armature. You may take it from me that the net result on any one coil is approximately the same as if that coil alone were moved, and all the other coils were fixed, and there were no reversals of current

FIG. 8.

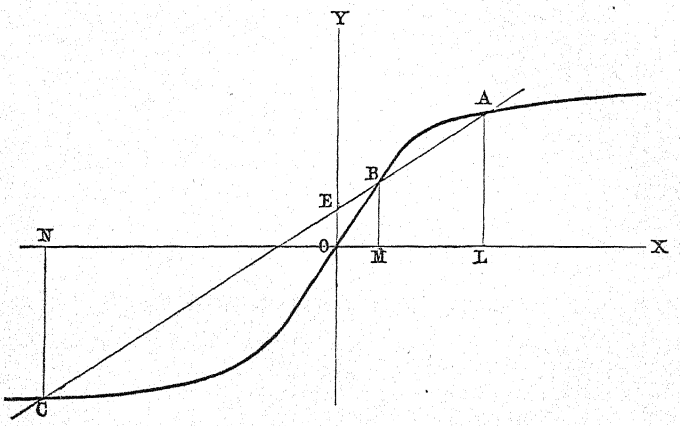


in them. Now you can easily see that the magnetic effect of the current circulating in the coils of the armature, will be to produce a north pole at *n*, and a south pole at *s*. This will displace the magnetic field in the direction of rotation. If, then, we were to keep the contact points the same as when no current was passing, we should short circuit the sections of the armature at a time when they were cutting through the lines of magnetic force, with a result that there would be vigorous sparks between the collecting brushes and the commutator. To avoid this, the brushes must follow the magnetic field, and also be displaced in the direction of rotation, this displacement being greater as the current in the armature is greater in proportion to the magnectic field. The net effect of this disturbing effect of the current in the armature reacting upon itself is then to displace the neutral points upon the commutator, and consequently somewhat to diminish the effective electromotive force. It is best to adjust the brushes to make contact at a point such that, with the current then passing, flashing is reduced to a minimum, but this point does not necessarily coincide with the point which gives maximum difference of potential. The magnetic field in the Gramme and other continuous dynamo-electric machines, may be produced in several ways. Permanent magnets of steel may be used, as in some of the smaller machines now made, and in all the earlier machines; these are frequently called magneto-machines. Electro-magnets excited by a current from a small dynamo-electric machine, were introduced by Wilde; these may be described shortly as dynamos with separate exciters. The plan of using the whole current from the armature of the machine itself, for exciting the magnets, was proposed almost simultaneously by Siemens, Wheatstone, and S. A. Varley. A dynamo, so excited, is now called a series dynamo. Another method is to divide the current from the armature, sending the greater part into the external circuit, and a smaller portion through the electro-magnet, which is then of very much higher resistance; such an arrangement is called a shunt dynamo. A combination of the two last methods has been recently introduced, for the purpose of maintaining constant potential. The magnet is partly excited by a circuit of high resistance, a shunt to the external circuit, and partly by coils conveying the whole current from the armature. All but the first two arrangements named depend on residual magnetism to initiate the current, and below a certain speed of rotation give no practically useful electromotive force. A dynamo machine is, of course, not a perfect instrument for converting

mechanical energy into the energy of electric current. Certain losses inevitably occur. There is, of course, the loss due to friction of bearings, and of the collecting brushes upon the commutator; there is also the loss due to the production of electric currents in the iron of the machine. When these are accounted for, we have the actual electrical effect of the machine in the conducting wire; but all of this is not available for external work. The current has to circulate through the armature, which inevitably has electrical resistance; electrical energy must, therefore, be converted into heat in the armature of the machine. Energy must also be expended in the wire of the electro-magnet which produces the field, for the resistance of this also cannot be reduced beyond a certain limit. The loss by the resistance of the wires of the armature and of the magnets greatly depends on the dimensions of the machine. About this I shall have to say a word or two presently. To know the properties of any machine thoroughly, it is not enough to know its efficiency and the amount of work it is capable of doing; we need to know what it will do under all circumstances of varying resistance or varying electromotive force. We must know, under any given conditions, what will be the electromotive force of the armature. Now this electromotive force depends on the intensity of the magnetic field, and the intensity of the magnetic field depends on the current passing round the electro-magnet and the current in the armature. The current then in the machine is the proper independent variable in terms of which to express the electromotive force. The simplest case is that of the series dynamo, in which the current in the electro-magnet and in the armature is the same, for then we have only one independent variable. The relation between the electromotive force and current is represented by such a curve as is shown in the diagram, Fig. 9 (p. 96). The abscissæ, measured along O X, represent the current, and the ordinates represent the electromotive force in the armature. When four years ago I first used this curve, for the purpose of expressing the results of my experiments on the Siemens dynamo-machine, I pointed out that it was capable of solving almost any problem relating to a particular machine, and that it was also capable of giving good indications of the results of changes in the winding of the magnets, or of the armatures of such machines. Since then Mr. Marcel Deprez has happily named such curves "characteristic curves." I will give you one or two illustrations of their use. A complete characteristic of a series dynamo does not terminate at the origin, but has a negative branch, as shown in the diagram; for it is clear that by reversing the current through the whole

machine, the electromotive force is also reversed. Suppose a series dynamo is used for charging an accumulator, and is driven at a given speed, what current will pass through it? The problem is easily solved. Along O Y, Fig. 9, set off O E to represent the electromotive force of the accumulator, and through E draw the line C E B A, making an angle with O X, such that its tangent is equal to the resistance of the whole circuit, and cutting the characteristic curve, as it in general will do, in three points, A, B, and C. We have then three answers to the question. The current passing through the dynamo will be either O L, O M, or O N the abscissæ of the points where the line cuts the curve. O L represents the current when the dynamo is actually charging the accumulator. O M represents a current which could exist for an instant, but which would

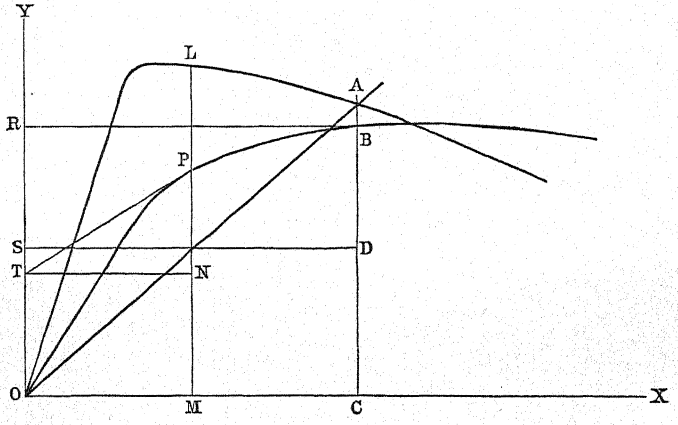
FIG. 9.



be unstable, for the least variation would tend to increase. O N is the current which passes, if the current in the dynamo should get reversed, as it is very apt to do when used for this purpose. The next illustration is rather outside my subject, but shows another method of using the characteristic curve. Many of you have heard of Jacobi's law of maximum effect of transmitting work by dynamo-machines. It is this. Supposing that the two dynamo-machines were perfect instruments for converting mechanical energy into electrical energy, and that the generating machine were run at constant velocity, whilst the receiving machine had a variable velocity, the greatest amount of work would be developed in the receiving machine when its electromotive force was one-half that of the generating machine, then the efficiency would be one-half, and the electrical work done by the generat-

ing machine would be just one-half of what it would be if the receiving machine were forcibly held at rest. Now this law is strictly true if, and only if, the electromotive force of the generating machine is independent of the current passing through its armature. What I am now going to do is to give you a construction for determining the maximum work which can be transmitted when the electromotive force of the generating machine depends on the current passing through the armature, as, indeed, it nearly always does, referring to Fig. 10. O P B is the characteristic curve of the generating machine; construct a derived curve thus, at successive points P of the characteristic curve, draw tangents P T, draw T N parallel to O X, cutting P M in N, produce M P to L, making L P equal P N; the point L gives the derived curve,

FIG. 10.

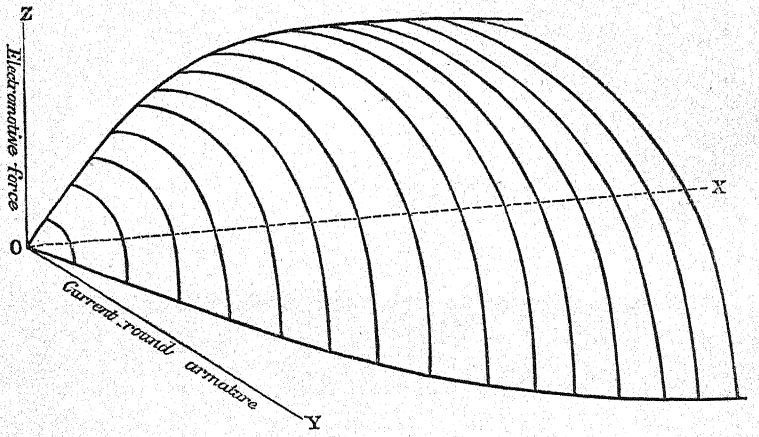


which I want. Now, to find the maximum work which can be transmitted, draw O A at such an angle with O X that its tangent is equal to twice the resistance of the whole circuit, cutting the derived curve in A. Draw the ordinate A C, cutting the characteristic curve in B; bisect A C at D. The work expended upon the generating machine would be represented by the parallelogram O C B R, the work wasted in resistance by O C D S, and the work developed in the receiving machine by the parallelogram S D B R.

When the dynamo-machine is not a series dynamo, but the currents in the armature and in the electro-magnet, though possibly dependent upon each other are not necessarily equal, the problem is not quite so simple. We have, then, two variables, the current in the electro-magnet and the current in the armature; and the proper representation of the properties of the machine will be by a

characteristic surface such as that illustrated by this model, Fig. 11. Of the three co-ordinate axes, O X represents the current in the magnet; O Y represents the current in the armature not necessarily to the same scale, and O Z the electromotive force. By the aid of such a surface as this one may deal with any problem relating to a dynamo-machine, no matter how its electro-magnets and its armature are connected together. Let us apply the model to find the characteristic of a series dynamo. Take a plane through O Z, the axis of electromotive force, and making such an angle with the plane O X, O Z, that its tangent is equal to current unity on axis O Y, divided by current unity on axis O X. This plane cuts the surface in a curve. The projection of this curve on the plane O X, O Z is the characteristic curve of the series dynamo. This

FIG. 11.



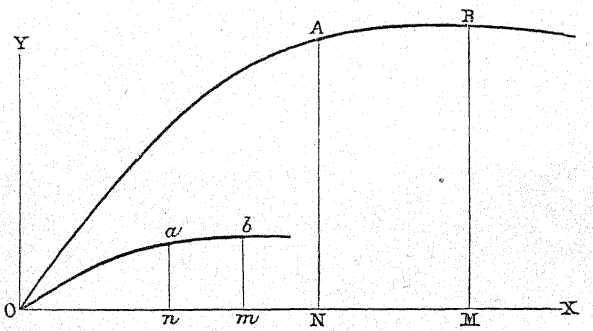
O X is current round magnet.

model only shows an eighth part of the complete surface. If any of you should interest yourselves about the other seven parts, which are not without interest, remember that it is assumed that the brushes always make contact with the commutator at the point of no flashing, if there is one. Of course in actual practice one would not use the model of the surface, but the projections of its sections. While I am speaking of characteristic curves there is one point I will just take this opportunity of mentioning. Three years ago, Mr. Shoolbred exhibited the characteristic curve of a Gramme machine, in which, after the current attained to a certain amount, the electromotive force began to fall. I then said that I thought there must be some mistake in the experiment. However, subsequent experiments have verified the fact; and when one con-

siders it, it is not very difficult to see the explanation. It lies in this: after the current attains to a certain amount the iron in the machines becomes magnetically nearly saturated, and consequently an increase in the current does not produce a corresponding increase in the magnetic field. The reaction, however, between the different sections of the wire on the armature goes on increasing indefinitely, and its effect is to diminish the electromotive force.

A little while ago I said that the dimensions of the machine had a good deal to do with its efficiency. Let us see how the properties of a machine depend upon its dimensions. Suppose two machines alike in every particular excepting that the one has all its linear dimensions double that of the other; obviously enough all the surfaces in the larger would be four times the corresponding surfaces in the smaller, and the weights and volumes of the larger would be eight times the corresponding weights in the

FIG. 12.



smaller machine. The electrical resistances in the larger machine would be one-half those of the smaller. The current required to produce a given intensity of magnetic field would be twice as great in the larger machine as in the smaller. In the diagram, Fig. 12, are shown the comparative characteristic curves of the two machines, when driven at the same speed. You will observe that the two curves are one the projection of the other, having corresponding points with abscissæ in the ratio of one to two, and the ordinates in the ratio of one to four. Now at first sight it would seem as though, since the wire on the magnet and armature of the larger machine has four times the section of that of the smaller, that four times the current could be carried, that consequently the intensity of the magnetic field would be twice as great, and its area would be four times as great, and hence the

electromotive force eight times as great; and since the current in the armature also is supposed to be four times as great, that the work done by the larger machine would be thirty-two times as much as that which would be done by the smaller. Practically, however, no such result can possibly be attained, for a whole series of reasons. First of all, the iron of the magnets becomes saturated, and consequently instead of getting eight times the electromotive force, we should only get four times the electromotive force. Secondly, the current which we can carry in the armature is limited by the rate at which we can get rid of the heat generated in the armature. This we may consider as proportional to its surface, consequently we must only waste four times as much energy in the armature of the larger machine as in the smaller one, instead of eight times, as would be the case if we carried the current in proportion to the section of the wire. Again, the larger machine cannot run at so great an angular velocity as the smaller one. And lastly, since in the larger machine the current in the armature is greater in proportion to the saturated magnetic field than it is in the small one, the displacement of the point of contact of the brushes with the commutator will be greater. However, to cut the matter, about which one might say a great deal, short, one may say that the capacity of similar dynamo-machines is pretty much proportionate to their weight, that is, to the cube of their linear dimensions; that the work wasted in producing the magnetic field will be directly as the linear dimensions; and that the work wasted in heating the wires of the armature will be as the square of the linear dimensions. Now let us see how this would practically apply. Suppose we had a small machine capable of producing an electric current of 4 HP., that of this 4 HP. 1 was wasted in heating the wires of the armature, and 1 in heating the wires of the magnet, 2 would be usefully applied outside. Now, if we doubled the linear dimensions we should have a capacity of 32 HP., of which 2 only, if suitably applied, would be required to produce the magnetic field, and 4 would be wasted in heating the wires of the armature, leaving 26 HP. available for useful work outside the machine—a very different economy from that of the smaller machines. But if we again doubled the linear dimensions of our machine, we should by no means obtain a similar increase of effect. A consideration of the properties of similar machines has another very important practical use. As you all know, Mr. Froude was able to control the design of ironclad ships by experiments upon models made in paraffin wax. Now, it is a very much easier thing to predict

what the performance of a large dynamo-machine will be, from laboratory experiments made upon a model of a very small fraction of its dimensions. As a proof of the practical utility of such methods, I may say that by laboratory experiments I have succeeded in increasing the capacity of the Edison machines without increasing their cost, and with a small increase of their percentage of efficiency, remarkably high as that efficiency already was.

I might occupy your time with considerations as to the proper proportion of conductors, and explain Sir W. Thomson's law, that the most economical size of a copper conductor is such that the annual charge for interest and depreciation of the copper of which it is made, shall be equal to the cost of producing the power which is wasted by its resistance. But the remaining time will, perhaps, be best spent in considering the production of light from the energy of electric currents. You all know that this is done commercially in two ways, by the electric arc, and by the incandescent lamp; as the arc lamp preceded the incandescent lamp historically, we will examine one or two points connected with it first.

I have here all that is necessary to illustrate the electric arc, viz., two rods of carbon supported in line with each other, and so mounted that they can be approached or withdrawn. Each carbon is connected with one of the poles of the Edison dynamo-machine, which is supplying electricity to the incandescent lamps which illuminate the whole of this building. A resistance is interposed in the circuit of the lamp, because the electromotive force of the machine is much in excess of what the lamp requires. I now approach the carbons, bring them into contact, and again separate them slightly; you observe that the break does not stop the current which forces its way across the space. I increase the distance between the carbons, and you observe the electric arc between their extremities; at last it breaks, having attained a length of about 1 inch. Now the current has hard work to cross this air-space between the carbons, and the energy there developed is converted into heat, which raises the temperature of the ends of the carbon beyond any other terrestrial temperature. There are several points of interest I wish to notice in the electric arc. Both carbons burn away in the air, but there is also a transference of carbon from the positive to the negative carbon; therefore, although both waste away, the positive carbon wastes about twice as fast as the negative. With a continuous current, such as we are using now, the negative carbon becomes pointed, whilst the positive carbon forms a crater or hollow; it is this crater which becomes most

intensely hot and radiates most of the light, hence the light is not by any means uniformly distributed in all directions, but is mainly thrown forward from the crater in the positive carbon. This peculiarity is of great advantage for some purposes, such, for example, as military or naval search-lights, but it necessitates, in describing the illuminating power of an arc-light, some statement of the direction in which the measurement was made. On account of its very high temperature the arc-light sends forth a very large amount of visible radiation, and is therefore very economical of electrical energy. For the same reason its light contains a very large proportion of rays of high refrangibility, blue and ultra-violet. I have measured the red light of an electric arc against the red of a candle, and have found it to be 4,700 times as great, and I have measured the blue of the same arc-light against the blue of the same candle, and found it to be 11,380 times as great. The properties of an electric arc are not those of an ordinary conductor. Ohm's law does not apply. The electromotive force and the current do not by any means bear to each other a constant ratio. Strictly speaking, an electric arc cannot be said to have an electric resistance measurable in ohms. We will now examine the electrical properties of the arc experimentally. In the circuit with the lamp is a Thomson graded current galvanometer for measuring the current passing in ampères; connected to the two carbons is a Thomson graded potential galvanometer, for measuring the difference of potential between them in volts. We have the means of varying the current by varying the resistance, which I have already told you is introduced into the circuit. We will first put in circuit the whole resistance available, and will adjust the carbons so that the distance between them is, so near as I can judge, $\frac{1}{8}$ inch. We will afterwards increase the current, and repeat the readings. The results are given in the following Table:—

Current Galvanometer.	Potential Galvanometer.	Ampères.	Volts.	Watts.	HP.
6·2	12·0	9·9	35	346	0·46
9·3	12·0	14·9	35	521	0·70
11·5	11·8	18·4	34	626	0·84

If the electrical properties of the arc were the same as those of a continuous conductor, the volts would be in proportion to the ampères, if correction were made for change of temperature; you

observe that instead of that the potential is nearly the same in the two cases. We may say, with some approach to accuracy, that with a given length of arc, the arc opposes to the current an electromotive force nearly constant, almost independent of the current. This was first pointed out by Edlund. If you will speak of the resistance of the electric arc, you may say that the resistance varies inversely as the current. Take the last experiment; by burning 4 cubic feet of gas per hour we should produce heat-energy at about the same rate. I leave any of you to judge of the comparative illuminating effects. It is not my purpose to describe the mechanisms which have been invented for controlling the feeding of the carbons as they waste away. Several lamps lent by Messrs. Siemens Brothers—to whom I am indebted for the lamp and resistance I have just been using—lie upon the table for inspection. An electric arc can also be produced by an alternate current. Its theory may be treated mathematically, and is very interesting, but time will not allow us to go into it. I will merely point out this,—there is some theoretical reason to suppose that an alternate-current arc is in some measure less efficient than one produced by a continuous current. The efficiency of a source of light is greater, as the mean temperature of the radiating surface is greater. The maximum temperature in an arc is limited probably by the temperature of volatilisation of carbon; in an alternate-current arc the current is not constant, therefore the mean temperature is less than the maximum temperature; in a continuous-current arc, the current being constant, the mean and maximum temperatures are equal, therefore in a continuous-current arc the mean temperature is likely to be somewhat higher than in an alternate-current arc.

We will now pass to the simpler incandescent light. When a current of electricity passes through a continuous conductor, it encounters resistance, and heat is generated, as was shown by Joule, at a rate represented by the resistance multiplied by the square of the current. If the current is sufficiently great, the heat will be generated at such a rate that the conductor rises in temperature so far that it becomes incandescent and radiates light. Attempts have been made to use platinum and platinum-iridium as the incandescent conductor, but these bodies are too expensive for general use, and besides, refractory though they are, they are not refractory enough to stand the high temperature required for economical incandescent lighting. Commercial success was not realised until very thin and very uniform threads or filaments of carbon were produced and enclosed in reservoirs of

glass, from which the air was exhausted to the utmost possible limit. Such are the lamps made by Mr. Edison with which this building is lighted to-night. Let us examine the electrical properties of such a lamp. Here is a lamp intended to carry the same current as those overhead, but of half the resistance, selected because it leaves us a margin of electromotive force wherewith to vary our experiment. Into its circuit I am able to introduce a resistance for checking the current, composed of other incandescent lamps for convenience, but which I shall cover over that they may not distract your attention. As before, we have two galvanometers, one to measure the current passing through the lamp, the other the difference of potential at its terminals. First of all, we will introduce a considerable resistance; you observe that, although the lamp gives some light, it is feeble and red, indicating a low temperature. We take our galvanometer readings. We now diminish the resistance, the lamp is now a little short of its standard intensity; with this current it would last 1000 hours without giving way. We again read the galvanometers. The resistance is diminished still further. You observe a great increase of brightness, and the light is much whiter than before. With this current, the lamp would not last very long. The results are given in the following Table :—

Current Galvanometer.	Potential Galvanometer.	Ampères.	Volts.	Watts.	Resistance Ohms.
5·2	12·8	0·38	37	14	97
6·0	14·3	0·44	41	18	93
11·5	23·4	0 84	68	57	81

There are three things I want you to notice in these experiments: first, the light is whiter as the current increases; second, the quantity of light increases very much faster than the power expended increases; and thirdly, the resistance of the carbon filament diminishes as its temperature increases, which is just the opposite of what we should find with a metallic conductor. This resistance is given in ohms in the last column. To the second point, which has been very clearly put by Dr. Siemens in his British Association address, I shall return in a minute or two.

The building is this evening lighted by about 200 lamps, each giving sixteen candles' light, when 75 watts of power are developed in the lamp. To produce the same sixteen candles' light in ordinary flat-flame gas-burners, would require between seven

and eight cubic feet of gas per hour, contributing heat to the atmosphere at the rate of 3,400,000 foot-pounds per hour, equivalent to 1250 watts, that is to say, equivalent gas lighting would heat the air nearly seventeen times as much as the incandescent lamps.

Look at it another way. Practically, about eight of these lamps take one indicated horse-power in the engine to supply them. If the steam engine were replaced by a large gas engine this 1 HP. would be supplied by 25 cubic feet of gas per hour, or by rather less; therefore by burning gas in a gas engine driving a dynamo, and using the electricity in the ordinary way in incandescent lamps, we can obtain more than 5 candles per cubic foot of gas, a result you would be puzzled to obtain in 16-candle gas burners. With arc lights instead of incandescent lamps many times as much light could be obtained.

At the present time, lighting by electricity in London must cost something more than lighting by gas. Let us see what are the prospects of reduction of this cost? Beginning with the engine and boiler, the electrician has no right to look forward to any marked and exceptional advance in their economy. Next comes the dynamo, the best of these are so good, converting 80 per cent. of the work done in driving the machine into electrical work outside the machine, that there is little room for economy in the conversion of mechanical into electrical energy; but the prime cost of the dynamo-machine is sure to be greatly reduced. Our hope of greatly increased economy must be mainly based upon probable improvements in the incandescent lamp, and to this the greatest attention ought to be directed. You have seen that a great economy of power can be obtained by working the lamps at high-pressure, but then they soon break down. In ordinary practice, from 140 to 200 candles are obtained from a horse-power developed in the lamps, but for a short time I have seen over 1000 candles per horse-power from incandescent lamps. The problem, then, is so to improve the lamp in details, that it will last a reasonable time when pressed to that degree of efficiency. There is no theoretical bar to such improvements, and it must be remembered that incandescent lamps have only been articles of commerce for about three years, and already much has been done. If such an improvement were realised, it would mean that you would get five times as much light for a sovereign, as you can now. As things now stand, so soon as those who supply electricity have reasonable facilities for reaching their customers, electric lighting will succeed commercially where other considerations than

cost have weight. We are sure of some considerable improvement in the lamps, and there is a probability that these improvements may go so far as to reduce the cost to one-fifth of what it now is. I leave you to judge whether or not it is probable, nay, almost certain, that lighting by electricity is the lighting of the future.

Mr. BRUNLEES, President, moved a vote of thanks to Dr. Hopkinson for his lecture, which would stand for all time as a very valuable contribution to a most important subject.

The vote was carried by acclamation.

19 April, 1883.

SIR J. W. BAZALGETTE, C.B., Vice-President,
in the Chair.

Electricity applied to Explosive Purposes.

By PROFESSOR F. A. ABEL,[1] C.B., F.R.S., Hon. M. Inst. C.E.

ALTHOUGH the subject which has been entrusted to me may not lay claim to such general public consideration and interest as those which have been so successfully and attractively dealt with by my colleagues, it certainly should not rank behind them in importance to such an audience as I have the honour of addressing; for the application of electricity to the development and efficient utilization of the force of explosive agents has proved of great value to every branch of engineering science, civil and military, mechanical and mining, while even the telegraph engineer has been concerned in the employment of explosives through electrical agency for the transmission of time-records.

The ignition of a charge of explosive through the agency of a match, a powder train, or a slow-burning fuze, though still very extensively practised in mining and blasting operations, and likely to continue so on account of its comparatively simple and inexpensive nature, presents such decided disadvantages in point of uncertainty, and in some cases of danger, when compared with the operation of firing by electricity, that it is not surprising to find on record, at an early period in the development of electrical science, attempts to apply an electric spark, or the heat developed by electrical currents under certain conditions, to the ignition of powder-charges. But it is especially in connection with the firing of charges under water, and with the execution of extensive operations of mining or demolition, when the safety of the operators can only be secured by their being at a considerable distance from the scene of operation at the time of the explosion, or in which the simultaneous explosion of a number of distinct and more or less separated charges is a matter of importance, that the value of

[1] Professor Abel received the honour of knighthood at the hands of the Queen on the following day.—SEC. INST. C.E.

electricity as an exploding agent is manifest. The mining fuze patented by Mr. Bickford, in 1831, effected an enormous improvement in the firing of mines, and failures with it are comparatively rare, unless it has deteriorated from careless keeping, or from the use of an imperfectly protected fuze in damp or wet places. But, even with this improved fuze in general use, many a fatal accident in military and industrial operations has resulted from the hanging fire of the fuze, and many failures and delays of vital consequence have resulted from the occasionally uncertain and capricious nature of igniting appliances of this class, and from the impossibility of ascertaining, when all arrangements are complete, whether the explosion prepared for will actually take place.

The possibility of applying the electric spark to the ignition of gunpowder suggested itself independently to Franklin, in America, in 1751,[1] and to Priestley in 1767, but it was not until some years after the discovery of the electric pile by Volta that serious attempts were made to apply electricity as the igniting agent of powder-charges used in mining and military operations. The first practical application of the voltaic battery in this direction was made about forty-five years ago by French military engineers, and a few years afterwards Sir Charles Pasley, whose name is so well known in the engineering world, was the first to bring the use of electricity in the firing of gunpowder to a practical issue in England. The art of firing powder-charges under water was in a very backward state when Colonel Pasley first made it the subject of practical investigation in 1812, and, finding that the slow-burning fuze subsequently invented by Bickford could only be used at comparatively small depths with any prospect of success, he devised a fairly efficient arrangement of powder hose, which could be led to considerable depths, and which he employed with some success in operating upon the wrecks of the "Royal George" and "Edgar," which were submerged in deep water off Spithead. It was while engaged in this work that Pasley, profiting by the counsels and instructions of Daniell and Wheatstone, carried out between 1835

[1] In his "Letters on Electricity," dated 29th June, 1751, Franklin says, "I have not heard that anybody in Europe has yet succeeded in firing gunpowder by means of electricity. We do it in this way: a small cartridge is filled with dry powder, which is rammed in tightly enough to crush a few grains; two pointed brass wires are then fixed in it, one at each end, so that their points are not further apart than half an inch at the centre of the cartridge, which is then placed in the circuit of the electric machine; when the communication is completed, the flame, leaping from the points of one wire to that of the other, through the powder in the cartridge, fires it instantaneously."

and 1840 the first blasting and mining operations by electrical agency which were accomplished on a practical scale in this country.

The Daniell battery was used in the earlier of these operations, upon the "Royal George" at Chatham, and upon some wrecks in the Thames, and some decided progress appears to have been made in blasting by electric agency, but in 1840 General Sir John F. Burgoyne, writing on the subject of rock-blasting in the Corps Papers of the Royal Engineers, said: "the distinct machinery for this purpose (firing by a voltaic battery), the expense, and probably some degree of nicety in its arrangements, even after all the improvements that have been made by Colonel Pasley, would render it inapplicable to ordinary purposes; although for firing very large quantities of powder, under very peculiar circumstances, it has been considered very useful simultaneous explosions, that are impossible by any other means, might be effected by this mode of ignition."

In the winter of 1842–3, experiments were instituted at Dover with the Daniell battery upon a considerable scale, preliminary to the explosion of the great mines, by which the destruction of the Round Down Cliff was accomplished on the 26th of January, 1843, when more than 40,000 cubic yards of rock were dislodged by the explosion of three chambers containing 18,500 lbs. of powder. A large copper- and zinc-plate battery, on the Wollaston principle, was actually used for that work, and was employed in subsequent operations upon the "Royal George," it being found to possess decided advantages, in point of power and simplicity, over the Daniell battery. In the concluding operations upon the wreck in 1843, a zinc and iron battery was successfully applied to the simultaneous explosion of several large charges. The conducting-wires leading from the battery to the mines, in those experiments, were not insulated by means either of gutta-percha or india-rubber; they were composed of strands of copper wire placed side by side, and insulated from each other and from the water by being coated with a mixture of beeswax, pitch, and tallow, and then bound over with layers of tape and twine, or rope-yarn. As acquaintance with the work became developed, the entire metallic circuit was dispensed with after a time, and the circuit was completed through the water, the surface of the metal case enclosing the charge being employed as one earth-plate, and large zinc sheets as the other.

The general method of operating pursued at that time by our military engineers was adhered to with little modification for

many years. In the centre of the charge of gunpowder was placed a so-called burster or fuze, a small box or case of wood, with two short copper wires passing to the interior and firmly fixed, the enclosed extremities being connected by a short bridge of thin wire, composed of metal of inferior conducting power; iron in the first instance, and afterwards platinum, which was surrounded by very fine grain powder. The protruding extremities of the copper-wires thus arranged were connected with the terminals of the circuit-wires by means of binding wire, the connections being covered with insulating wrappings. The heating to redness of the fine wire-connection or bridge (or its fusion, in the case of iron being used), consequent upon the resistance which it opposed to the current, ignited the fine grain powder by which it was surrounded, and the charge was thereby exploded. Simple self-acting arrangements were used for causing the battery-wires to be short-circuited for a sufficient time after the arrangement of a mine was completed, to allow the operators to reach a place of safety, the current passing through the entire circuit, and thereby firing the fuze, at a fixed period.

In an interesting memoir on the explosion of powder, written in 1845 by Captain Hutchinson, R.E. (now General Hutchinson, of the Board of Trade), and published in the "Aide Mémoire to the Military Sciences," the forms of battery successively tried in connection with the earliest experimental operations, and with the destruction of the "Royal George" and the Round Down Cliff, are described, as also the methods used for preparing insulated wires, electric fuzes or bursters, and charges for submarine operations; for firing the charges by self-acting arrangements, and for testing the circuit and the fuzes, before combining them. For the latter purpose the use "of the instrument called the galvanometer" is prescribed, as affording the readiest mode of testing; the action of the needle is stated to be more readily visible if the coil surrounds it vertically, and the test-battery prescribed is either "a small plate of zinc within a copper case," or a "small single cell of a Daniell battery, by which the action will be much longer kept up, and the zinc will not so soon perish." The "water-test apparatus" (Voltameter) is also indicated as another method of "proving the completeness of a circuit, requiring, however, a more powerful battery, and not being so quickly performed as by the galvanometer." The methods of working pursued in 1843 at Spithead, at the Phœnix Park operations of Captain Larcom, and at the Round Down Cliff, are also described. At the latter place it consisted simply in firing the individual charges by separate batteries

through wires 1000 feet long, by word of command, but in the other operations the charges were connected by branch-wires with the main wires, either by attaching them with binding-wire, or binding-screws, to those wires at convenient intervals, or by leading one wire from each charge to a mercury-cup, and the other wire to a second cup, the bare extremities of the double main wire being immersed in the two cups, when it was desired to complete circuit with the battery. This method of arranging the charges in branch- or fork-circuits, by which the current is made to distribute itself so as to heat the wire bridges introduced into the several circuits simultaneously, was afterwards applied by the French electrician, Savare, for utilizing a rapid succession of currents of high tension, as will be presently pointed out.

As a whole, the manner in which the operations of forty years ago were carried out, evinced a sound knowledge of the principles of electrical science, and considerable practical skill and ingenuity in their application by the Royal Engineer officers who devoted themselves to this work.

The copper-zinc battery continued for some time in use as the exploding agent for military service, but some improvements were gradually introduced into the methods of operating, by Royal Engineer officers. Colonel Ward, more especially, did very useful work in this direction, and published in the "Aide Mémoires" of the Royal Engineers for 1854, the results of a very careful investigation of the merits of different batteries, and of the conditions to be fulfilled in operating through different lengths of wire-circuit, with details on the construction of the fuzes and arrangement of charges for simultaneous explosions, and other important points. One result of his labours was the adoption for military service of a form of Grove battery specially adapted to work of this kind, which, with the rough form of platinum-wire fuze described, continued in use until, soon after a report by Sir C. Wheatstone and the Lecturer was presented to the War Office, in 1860, which will presently be referred to again, instruments developing currents of high tension gradually displaced voltaic batteries as exploding agents.

Although the employment of a voltaic current of low tension presents obvious and great advantages over old systems of igniting charges by trains or slow-burning fuzes, its application to military purposes is attended with some difficulty and uncertainty, arising out of the want of uniformity of action of one and the same Voltaic arrangement at different periods, the difficulties attending the transport, and proper preservation of the battery and materials required

for its use, the dependence for success upon care and experience in preparing and preserving the batteries, and the very considerable increase which it is necessary to make in the power of the battery when the operations to be performed involve the simultaneous explosion of a number of charges, or the ignition of gunpowder at very considerable distances from the battery.

Thus the Grove's battery, as arranged by Colonel Ward, though efficient when in thorough working order, possessed the very serious defect of want of constancy; within a comparatively brief period of its being set in action, even though not actually at work, it began to lose power to a certain extent, and in order to place proper reliance upon its efficiency when called into operation, it had to be dismounted, cleaned, and remounted, at least every twelve hours, so that, besides maintaining a large reserve of the difficultly transportable porous cells, it was necessary, on active service, to provide the requisite battery-power in duplicate, besides using a number of cells considerably in excess of the theoretical requirements.

For reasons of this nature, soon after the first successful application of voltaic electricity to mining purposes, the attention of military engineers on the Continent, and of others here and abroad who were specially interested in operations of this kind, became directed to the possibility of rendering electricity of high tension available for exploding purposes, whereby voltaic batteries, for mining operations, might be greatly reduced in size, if not altogether dispensed with. In 1853 a Spanish officer, Colonel Verdu, associated himself with Mr. Ruhmkorff in experiments on the application of electro-magnetic induction coils to the explosion of gunpowder. The success of these experiments led Verdu to pursue them further in Spain, where he soon succeeded in firing six mines simultaneously by one element of Bunsen's battery, at a distance of upwards of 300 yards, through the agency of the Ruhmkorff coil. The mode of operation and the difficulties which Verdu had to overcome will be presently described. While his success led the military engineers in Spain, France, and Russia to pursue the development of the application of electro-magnetic induction-instruments to exploding purposes, a committee of Austrian military engineers (of which Baron von Ebner was from the first a most distinguished member) was labouring to apply frictional electricity to military uses as an exploding agent, they having come to the conclusion that the electro-magnetic induction apparatus was too complicated and too easily susceptible of derangement for military uses.

But little success had up to that time attended attempts to apply frictional electricity to this purpose. In 1831 Moses Shaw, of New York, succeeded in exploding several mines simultaneously by means of frictional electricity, with the employment of fuzes containing an admixture of fulminate of silver with gunpowder, but he was foiled in his attempts to apply this agent to practical purposes by the fact that he could not conduct operations with any chance of success except in very dry weather. Somewhat more promising results attended several attempts in Germany by Warrentrap and Götzmann, between 1842 and 1845, and in the latter year Mr. Charles Winter succeeded in firing a powder-charge by means of a sensitive fuze and a Leyden jar through the telegraph line between Vienna and Hetzendorf, a distance of 5,390 yards. But the prospect of practical success was still not encouraging when the Austrian committee of engineer officers took the matter in hand, and eventually produced a portable glass frictional electric machine, which, when in good working order, furnished results surpassing those hitherto obtained with volta-induction apparatus. Some very extensive operations were conducted with this machine; thus, fifty land-charges, and afterwards thirty-six submarine charges, were simultaneously exploded. Even, however, with all the precautions adopted, the machine was still too seriously affected by damp to be thoroughly serviceable for military purposes, while the induction action of the firing charge was sometimes so energetic that explosions were occasionally determined in mines not intended to be fired, and not connected with the electrical machine. But the persevering labours of Von Ebner eventually resulted in the production of an electric machine which was free from most of the objections hitherto attached to this form of apparatus.

While the progress just indicated was being made in different parts of the Continent in the application of electricity to mining operations, but little was done in this country towards effecting radical improvements in the utilization of electricity for industrial or military mining purposes. In 1855, however, Sir C. Wheatstone directed the attention of Field-Marshal Sir John F. Burgoyne to the importance of instituting an experimental inquiry into the relative advantages of different sources of high tension electricity as agents for exploding gunpowder. The Ordnance Select Committee, of whom Sir C. Wheatstone and Mr. Abel were then members, were consequently instructed to pursue this inquiry; and a series of investigations was carried out, in the first instance by a working branch of the Committee, and subsequently by Mr. Abel at Woolwich and Chatham, the results of which were

eventually embodied in a report presented by the above-mentioned gentlemen to the Secretary of State for War in 1860.

Meanwhile the subject of the application of electricity to the firing of mines, &c., continued to receive attention in Austria and other countries, and considerable impetus was given to work in this direction by the efforts of the two opposing powers in America, between 1862 and 1865; to apply electricity as the exploding agent of submarine mines, the prominent part played by these in the Civil War having had the effect of directing the attention of England and other nations to the prominent *rôle* likely to be played in future wars by methods of submarine attack and defence, and to the importance of applying the resources of electrical science to their development.

Before glancing at the important applications of electricity in this and similar directions which have been made and perfected during the past eighteen years, it will be instructive to examine briefly the results obtained with different sources of electricity in their application to explosive purposes, and the manner in which electric currents or discharges are made available to the explosion of powder under the various conditions and difficulties to be met in the fulfilment of military and industrial requirements.

It has been stated that Colonel Verdu succeeded, in 1853, in exploding several mines simultaneously by means of a Ruhmkorff induction-coil. The ignition of the gunpowder was effected in these experiments by introducing one or more small but complete interruptions into the circuit, across which the electric spark of high tension would leap upon the current being passed. This spark will inflame gunpowder, but not very readily, although its production is attended with development of heat considerably in excess of that necessary; the reason being that powder requires for its ignition either the close proximity of a considerable heated surface, or the continuous application of heat for a brief period, while the disruptive discharge from an induction-coil consists of a series of instantaneous discharges following each other in very rapid succession. Hence a charge of gunpowder is not always instantaneously fired when a series of sparks is passed; indeed, unless the powder be closely confined round the wire terminals between which the spark passes, it is sometimes dispersed by the mechanical action of the discharge without being exploded; and when a succession of sparks is passed simultaneously through a number of charges, it frequently occurs that only a few are exploded, in which some of the grains happened to be in positions or under conditions more favourable to

the action of the source of heat than in other instances where the powder escaped ignition. It need scarcely be stated that the same difficulty is experienced in attempts to apply the discharge from a frictional electric machine or Leyden jar to the explosion of powder; Moses Shaw was the first to overcome it by exposing to the action of the spark a mixture of powder with a much more readily explodable material; Verdu succeeded similarly, in increasing the certainty of simultaneous ignition of several charges by the spark from an induction coil-machine, by surrounding the wire terminals with a substance much more readily inflamed than powder, the fulminate of mercury. Another source of difficulty in effecting the simultaneous ignition of a considerable number of charges by the spark from an induction coil is the enfeebling effect upon the spark-discharge exerted by a number of successive small interruptions in the circuit. This was to some extent overcome by employing a fuze constructed by Messrs. Statham and Brunton, in which the space between the wire terminals was bridged over by a film of finely-divided substance—the subsulphide of copper, the conducting power of which is sufficiently great to aid the passage of the electric discharge across the interruption, while it is at the same time readily combustible, and therefore directly promotes the ignition of the powder.

The invention of the Statham and Brunton fuze may be regarded as the starting-point in the production of so-called high tension fuzes, as contra-distinguished from the thin wire- or low-tension fuze, and the circumstances which led to its construction therefore present special interest. In August 1851 a length of copper wire which had been covered at the Gutta-percha Company's Works with gutta-percha containing about 10 per cent. of sulphur, was being passed through water from one reel to another for the purpose of discovering what appeared to be a fault in insulation, when suddenly a bright spark was observed in the water. On examining the wire at that particular spot it was found to be broken and the gutta-percha burnt. Several pieces of similarly covered wire were then purposely broken, in each case with similar results. A length of the gutta-percha was then removed from the wire, and on applying the two poles of one hundred cells of the battery in use at various distances to the inner surface which had been in contact with the copper, and had become coated with a film of sulphide of copper, which in comparison to copper is of very high resistance, heat was generated, in proportion of course to the distance of the poles. Gunpowder was placed upon the gutta-percha, and on applying the battery-poles it was imme-

diately ignited. Consequently, by removing a small portion of the gutta-percha from the upper surface of the wire, then severing the latter at that point and slightly separating the two extremities, a suitable fuze for igniting explosive substances at long distances, and simultaneously at several points, was produced. When the cable was laid from Dover to Calais in September 1851, cannon were fired by the aid of these fuzes at Dover by a person at Calais, and *vice versâ*. Also when the first Mediterranean cable was laid from Spezzia to Corsica, a distance of 90 miles, similar experiments were successfully made.

Colonel Ward, in his important paper already mentioned, on the application of the voltaic battery to the explosion of powder, carefully examined into the properties of this fuze, and compared its behaviour with that of the wire fuze; he pointed out that, while the amount of heat required to ignite the sulphur- and copper-compound formed on the surface of the gutta-percha was very much less than that needed for firing a platinum wire-fuze, the conducting power of the substance was very low; but that whatever number of cells (roughly speaking) it is found necessary to arrange in series to produce ignition of the fuze at a distance of 1 foot by conduction of the current across the interrupted metallic circuit bridged over by the sulphide, will produce the same effect through a copper wire circuit of 1 mile, and that an addition of about one-fourth the number of cells of the battery will permit one-half of the copper circuit to be replaced by ordinary moist earth, the resistance of the fuze being so great that a large addition to the metal circuit, or the introduction of a great distance of earth-circuit, effects no material diminution in the actual quantity of electricity circulating. The battery used by Ward in his instructive experiments with these fuzes was a zinc- and copper sand battery 4 inches by 4 inches, of which one hundred plates were needed to fire the fuze with certainty, while three hundred plates of the same battery were not found to develop any sensible heat in the platinum-wire fuze, and he pointed out the important bearing of the internal resistance of this battery upon the attainment of these results. He also showed that, while the diameter and material of the metallic conductor are matters of material consequence in using the platinum-wire fuze, it is of no consideration to know the resistance of the conductor in the case of the Statham-Brunton fuze. On the other hand he insisted upon absolute insulation of the conductor as essential to the successful employment of this fuze.

While Ward was engaged upon experiments with this fuze

in 1854, it was demonstrated to him by the late Mr. Southby, a well-known pyrotechnist who devoted himself much to experimental electricity, that the current induced in a secondary coil, wound round a helix of the primary conductor through which the current from three or four cells of a Grove's battery was passed, sufficed to ignite the Statham-Brunton fuze. Ward found that, with such a helix, and four cells of Grove's battery 4″ × 4″, he could fire the fuzes at a distance of 1,300 yards from the operator (the longest distance he was able to try), and with the employment of a return earth circuit. These results were therefore obtained in England concurrently with, if not before, those which Colonel Verdu obtained with the excellently-constructed coil of Ruhmkorff.

The employment of the Statham fuze for effecting simultaneous explosions was not pursued to any great extent by Ward, but so far as his experiments went, with the use of the sand-battery, he found that the difficulties were much greater than those to be encountered with the platinum wire fuze. Even with the use of the Ruhmkorff induction coil, and with a priming of mercuric fulminate added to the Statham fuze, Verdu found that the number of charges which he could fire simultaneously was very limited. He was, however, able to obtain a fair result by the following simple arrangement. Separate small groups of mines were all connected with earth, and an insulated conducting wire connected each group with one of a series of small insulated plates. By bringing these in very rapid succession into circuit with the coil-machine, the several groups were so rapidly exploded as to produce results somewhat similar to those attainable by the really simultaneous discharge of a considerable number. Not long after this contrivance was adopted by Verdu, Savare applied the so-called branch-circuit-arrangement, whereby a much more rapidly successive discharge of a number of mines was accomplished through the agency of the coil. The metallic circuit which passed to the mines was divided into a number of branches, so that upon completion of the circuit the currents, following each other in very rapid succession, would distribute themselves through all the branches with a degree of uniformity regulated by the resistance met with in each branch. Thus, when one or more fuzes were interposed in each branch of the circuit, those which happened to offer the greatest facilities for the passage of the current would be first fired, whereupon the escape of electricity in that direction would be interrupted, and the explosion of fuzes in another branch would follow. With the employment of currents succeeding each other with the enormous rapidity with which they

pass off from the induction-coil machines, the discharge of a number of mines is thus accomplished in such very rapid succession as almost to have the effect of a simultaneous discharge. It will be seen that this arrangement is the same in principle as that used by Royal Engineer officers in England and Ireland in 1843, when first the voltaic battery was applied to the ignition of powder.

The Ruhmkorff coil was used to some extent by the Russians in mining operations during the Crimean War, and some very extensive operations were carried out with its aid at Cherbourg in 1854 by Dussaud and Rabattu, according to a system arranged by Du Moncel. In the first of these six mines, containing many thousand kilograms of powder, were simultaneously exploded, displacing more than 50,000 cubic metres of rock. A series of experiments was instituted by the Lecturer in 1856 with two excellent induction coils, produced by Ruhmkorff, in the course of which various descriptions of priming materials were tried in the fuzes, for the purpose of increasing the power of the machine to fire numbers of charges simultaneously. At that time the fulminate of mercury was found to be the best inflaming agent, but not more than twelve charges were fired simultaneously by means of the most powerful coil available and a battery of twelve cells (without employing Verdu's or the fork-method of explosion). One defect in this class of instrument was found to be the want of uniform action of one and the same apparatus at different periods; another was the liability to derangement of the machine, especially of the condenser. Far more successful results were afterwards obtained with the same coils, and the fuze constructed at a later period of the Woolwich investigations; fifteen charges were fired simultaneously with a battery of six cells, and fifty charges, arranged in branch-circuits in groups of ten, were exploded with the effect of a simultaneous discharge. These results were obtained with machines produced by Ruhmkorff in 1855; but the improvements since then effected in the construction of this apparatus have reduced to insignificance the results at that time obtained with it. There is no question, therefore, that induction-coil machines are available for special operations of considerable magnitude; but in point of simplicity, certainty, and constancy of action, they are far surpassed by other forms of electric instruments now in general use for explosive purposes.

At the suggestion of Sir Charles Wheatstone, experiments were commenced at Woolwich, in 1856, on the application of currents induced by permanent magnets to the explosion of

gunpowder. The first were instituted with a very large and powerful magneto-electric machine, constructed by Mr. Henley, of which the armature, carrying two powerful coils, was suddenly detached from the magnet by means of a lever. A few experiments sufficed to show that the induced current obtained even with this powerful instrument was not adequate to ignite one single charge of gunpowder with certainty. Somewhat better, but still uncertain, results were obtained with Statham's and one or two other forms of fuzes existing at that time.[1] A careful investigation was then undertaken by the Lecturer (with the invaluable assistance of Mr. E. O. Brown) into the conditions to be fulfilled in the production of a fuze which should be certain of action with the magneto-electric machine. The results of extensive experiments indicated that a combination of comparatively high conducting power with great susceptibility to ignition appeared to include essential elements of success in a material to be used as the exploding agent in such a fuze. The uniform arrangement of the poles, or wire terminals, in the fuze, the space between which was to be bridged over by the igniting composition, also proved a matter of great importance. A mode of constructing fuzes which ensured great uniformity in this respect was ultimately perfected, and has proved quite successful. This consists in the enclosure of two fine copper wires side by side in gutta-percha, by which material they are also uniformly separated from each other, so that great similarity as to distance between the poles, or exposed sections of the wires, is attained by simply cutting pieces of the double-covered wire off a long length of the same.

A fairly efficient fuze was obtained, with the aid of the poles thus arranged, by employing as the igniting agent gunpowder impregnated with a small proportion of calcium chloride, which caused it, on brief exposure to air, to imbibe moisture sufficient to render the gunpowder highly conducting. It is obvious, however, that there must be a liability to want of uniformity in the proportion of water absorbed by the powder, and a consequent variation in the conducting power of the latter. Eventually a material was prepared (consisting of the subphosphide of copper, subsulphide of copper and potassium chlorate) which combined the essentials of perfect certainty of action with very great sensitiveness to ignition. Henley's large magnet fired three of these fuzes in simple circuit

[1] A fuze which gave better results with this magneto-electric machine than any then existing was prepared by the late Mr. Henley. Its nature was not, however, disclosed by him.

with certainty, while a small horse-shoe magnet with revolving armature exploded twenty-five in divided circuit in exceedingly rapid succession. A combination of six small compound magnets was afterwards employed with which an exceedingly rapid succession of currents was obtained; and this apparatus exploded twenty-five fuzes, in divided circuit, with a rapidity which on the ear had the effect of an instantaneous explosion. Even the small magneto-electric instruments used for medical purposes will explode these fuzes without fail.

It may be mentioned, in illustration of the difficulties to be grappled with in such an inquiry as led to the production of this fuze, that the first phosphide of copper mixture employed in the priming of these high-tension fuzes contained finely-divided coke as the conducting medium (in place of the sulphide of copper afterwards used), and that, so far as uniformity and permanence were concerned, this mixture left little to be desired. But in the course of searching experiments with such fuzes, a slight residue, consisting chiefly of the coke employed, was found occasionally to remain between the closely contiguous poles of the fuze, after its ignition, and to form a connecting link or bridge between them, which interfered with the firing of other fuzes in the arrangement, by completing the circuit through that one, and thus preventing the rapidly successive currents from a magneto-electric machine from performing work upon others in branch-circuits. The substitution of the readily combustible and dispersable subsulphide of copper for the coke conquered what appeared likely to prove a formidable difficulty.

The application of magneto-electric machines having been successfully accomplished a series of experiments was carried on by the Lecturer, with the valuable aid of General H. Y. D. Scott, R.E., at Chatham, during the years 1857–58, on the explosion of charges, both land and submarine; and the great advantages of these instruments, as regards simplicity and permanent efficiency, over the voltaic arrangements then in use, was fully demonstrated. Very compact but powerful exploding instruments were constructed by Wheatstone, and these have received many important applications; thus the proof of cannon at Woolwich and the firing of guns, from a safe distance, in the numerous experiments at Shoeburyness, is effected by means of Wheatstone's exploder, which is, moreover, an important adjunct in all electro-ballistic experiments, when the operator desires himself to fire a gun at a particular moment. Magneto-electric machines have also been found very useful in connection with blasting operations on land, and in

mines, except in instances when the absolutely simultaneous explosion of a large number is required.

When the success of Wheatstone's exploders had been fully established several other forms of magneto-electric machines were devised, especially on the Continent and in America. Powerful instruments, similar to Wheatstone's, were manufactured by Siemens and Halske, of Berlin; Markus, of Vienna, constructed very efficient instruments in which one separation and return of the armature to the magnet are made to explode the charges. The disadvantages of these instruments is that a succession of currents cannot be obtained from them as in the case of machines with revolving armatures; hence the number of mines which can be exploded by them in divided circuit is limited. Mr. Beardslee, an American electrician, also devised a modification of Wheatstone's exploder, in which the magnets are made to revolve between the armature coils, and which furnishes currents of greater quantity but lower tension than Wheatstone's. A fuze was constructed by Beardslee for employment with this instrument similar in principle of construction to Abel's; the materials which bridge over the space between the terminals or poles of the fuze are blacklead, with the addition of a minute quantity of a substance, apparently collodion, which adds to the size of the scintillations produced when the current passes, and thus increases the certainty of ignition of the powder which is in close contact with the poles. These fuzes are efficient with magneto-electric instruments which, like that of Beardslee, furnish currents of comparatively low tension, but they are much less delicate than the Woolwich fuzes, and the number which can be simultaneously exploded is therefore more limited. Wheatstone also constructed more powerful modifications of his original magnetic exploder, which might at will be made to furnish currents of greater quantity and lower tension, or to produce the high-tension currents. Lastly, Ladd, Browning, and Breguet produced instruments of comparatively low price, but quite powerful enough for ordinary blasting and quarrying operations. The only obstacle, but a most important one, to the general use of these machines for the explosion of mines on land and under water is, that very slight defects in the insulation of the conducting wire which leads from the instrument to the mines are fatal to their exploding power. In consequence of the high tension of the current developed by them, and the small quantity put into circulation by even the most powerful, the complete diversion of the current from its destined course to earth is promoted by the

smallest points of escape presented to it; a result which is, moreover, facilitated by the very high resistance of the fuzes in circuit. With care this source of failure can be guarded against in operations on land, but such is not the case with regard to submarine arrangements; while, moreover, very minute defects in the coatings of the wires when submerged, which would hardly influence the results at all on land, completely nullify the exploding power of the machines. Hence magneto-electric instruments are the least reliable of all electric exploding apparatus for submarine purposes.

A few experiments were instituted at Woolwich in 1857 on the employment of frictional electricity as an exploding agent, and especially with a small hydro-electric machine constructed for the purpose by Sir William Armstrong. The power of this machine to explode a number of charges simultaneously, when it was in good working order, far surpassed any other instrument experimented with at that time; one hundred fuzes, arranged in simple circuit, were frequently exploded by its means; but the great uncertainty of its action, and the difficulty of employing it in the field, did not afford encouragement for continuing experiments with it.

The great difficulties encountered in the Austrian experiments, in attempts to employ glass frictional electric machines for military purposes, led Baron von Ebner to direct his attention to the production of an instrument in the construction of which glass was altogether avoided, and which might therefore be expected to be less subject to atmospheric influences. His labours in this direction were eventually crowned with success; for he found in the hard vulcanized india-rubber (known as ebonite or vulcanite) a dialectric material excellently adapted to the construction of the frictional apparatus; while by employing a sheet of soft vulcanized india-rubber, coated with tinfoil and compactly rolled up, he obtained without the use of glass a powerful condenser, or Leyden jar arrangement. The improved machines were constructed in a very compact form (with cases excluding all the working parts from direct exposure to air) by Messrs. Siemens of Berlin, and Lenoir of Vienna, who exhibited specimens in England in 1862, at which time the electric machine had already received important applications, been regularly adopted for military use in Austria. Von Ebner had also, from the commencement of his experiments, laboured assiduously at the production of an efficient fuze to be used with electricity of tension; and the Austrian service is indebted to him for a simple and thoroughly serviceable fuze, which, as regards the arrangement of its poles, and the character of the igniting composition,

may be said to combine the principles of the Statham and the Abel fuzes. Though much less sensitive than the Abel fuze, a very considerable number may be exploded in single circuit by the ebonite electric machine. The power of this apparatus in its most portable form is nearly equal to that of the hydro-electric apparatus just now referred to, when the latter was in perfect working order, and a far greater number of mines may therefore be simultaneously exploded by its means than by very large batteries, or by the most powerful portable magneto-electric machines hitherto constructed. One hundred Abel fuzes have frequently been simultaneously exploded with one of the portable machines, and still greater results can be obtained with a larger instrument, having a battery of condensers, which was specially constructed by the late Mr. Becker, at the suggestion of Captain Maury, and designed for use in connection with land- and submarine mines. In very damp weather, when the most perfect glass electric machines would have been useless unless housed in a warm apartment from which the external air was excluded as much as possible, these ebonite machines have been used from time to time throughout the day with very satisfactory results.

Another important advantage which they possess over magneto-electric machines, consists in the fact that very considerable defects in the insulation of even submerged conducting wires do not so greatly reduce the power of the current they furnish as to interfere with the accomplishment by its agency of the most extensive operations under water likely to occur in practice. Unfortunately, however, the very circumstance which constitutes their chief advantage, viz., the powerful character of the current of high tension with which they charge an insulated wire, is also a source of serious defect, to be presently noticed, which very greatly limits the usefulness of these machines for naval and military purposes.

Other more recent Continental and American forms of frictional machines constructed of vulcanite or ebonite, in some of which fur is used as the exciting agent and different forms of condensers are employed, are in favour in different countries or mining districts, and one of the most compact and efficient exploding instruments, excellently illustrating the simplicity to which machines of this class can be reduced by ingenuity and a thorough knowledge of the conditions to be fulfilled by a really practical apparatus, is the frictional electric exploder, manufactured of various dimensions by Laflin and Rands, of New York, in the form of an ebonite cylindrical box (or disk), on which the only

protruding objects are the connecting screws for wires and the handle for working the machine. When the handle has been turned sufficiently to charge the enclosed condenser, a reversal in motion of the same discharges the latter and fires the mine. This machine has been found specially valuable in boat-work, under conditions when it would have been very difficult to use any other form of frictional machine, and when other electric exploding apparatus depending for their operation upon mechanical arrangements, more or less accessible, would have sustained injury from the effects of contact with water, or an atmosphere laden with moisture, or salt-water spray.[1]

Although ebonite frictional electrical machines held their own for some considerable time, as the most powerful and generally effective exploding apparatus, for extensive operations they had to make way for a class of machine which, as combining general efficiency with simplicity, power, permanence, and independence of any influence emanating from atmospheric or local conditions, now occupy decidedly the highest position as practically useful agents for developing explosions. It is scarcely necessary to say that the machines referred to are those known as dynamo-electric, the first conception and elaboration of which we owe to Werner and William Siemens, Wheatstone, and others.

The action of the most simple form of these instruments may be described as follows:—The residual magnetism existing in an electro-magnet suffices to develop an induced current in a rapidly-revolving coil-armature; this current, re-acting upon the electro-magnet, determines the development of powerful magnetism in the latter by the inductive action of its insulated coils; the currents developed by the electro-magnet are consequently in their turn greatly increased in power, and re-act again upon the armature; and thus a great accumulation of electric force is very rapidly accomplished. When that accumulation has reached the maximum attainable without detriment to the insulation of the wire coils, a simple interrupting arrangement causes the current to be diverted from the machine to conducting-wires, by whose medium it is utilized. The details of the machines vary according to the different plans adopted by the several constructors, but the above explanation applies more particularly to the earlier machines of Siemens and Halske, who were the first to pro-

[1] One defect of ebonite in its application to the construction of frictional machines, is that the surface becomes roughened and worn after a time by the amalgam used in the cushions, so that the disks require re-polishing occasionally.

duce a small instrument of this class thoroughly applicable to mining purposes, and almost equal in power to the ebonite frictional-electric machine. Fifty Abel fuzes, arranged in simple circuit, have been repeatedly exploded without any failures by one of these machines; it therefore provides with certainty the power necessary for the most extensive land- or submarine mining operations, and is at the same time quite free from all disturbing atmospheric influences. Its mechanism is simple, and less easily susceptible of derangement than that of most magneto-electric apparatus; and as it is independent of everything but the application of manual power for the development of its action, it is far superior to the most perfect of these, independently of the fact that it surpasses them all greatly in power.

Various improvements have been introduced into these dynamo-electric exploders by Siemens Brothers, some at the instigation of the Royal Engineers Committee, at whose recommendation this instrument was adopted some years ago as the military service exploding machine. Other modifications of the dynamo-electric machine have recently been applied in forms suitable for use as a portable mine-exploder; a small description of Burgin's machine, and a very simple American ratchet machine, are among the most efficient of the dynamo-exploders now constructed.

The Siemens high tension dynamo-electric machine now used in the Royal Engineer service, and which is not too heavy to be carried some distance by one man, is capable of firing between 120 and 150 Abel fuzes in continuous circuit, and over 200 in two parallel circuits.

Although the phosphide of copper fuze was specially designed for use with generators of high-tension electricity, susceptible of advantageous employment as substitutes for voltaic batteries, its great sensitiveness to ignition rendered it equally available with voltaic piles, or batteries of high internal resistance, and this circumstance has exercised an important influence upon the rapid development of methods of applying electricity to important uses connected with naval offensive and defensive warfare.

It has been pointed out that magneto-electric instruments cannot be relied upon for submarine operations, on account of the very perfect insulation of the conducting-wires, joints, &c., required to ensure success with them. On the other hand, frictional electric and dynamo-electric machines supply ample power for the simultaneous ignition of numerous submarine mines, even through cables in the insulation of which some defects exist. Hence, when any extensive submarine operation has to be accomplished, these

machines may be used with advantage; but, for reasons to be presently pointed out, the frictional machine cannot be used as the exploding agent in connection with a system of submarine mines, of which it may be desired to explode any one particular mine, while leaving others in its vicinity intact. Dynamo-electric machines share this disadvantage with the frictional machines, when applied in conjunction with high-tension fuzes. In addition to the special attention required by both these classes of machines, in localities where they might be applied to submarine operations, there is one general objection to the use, in connection with naval and military operations, of any source of electricity, the development of which is entirely dependent upon manual operations to be performed at the instant an electric discharge is required, namely, that, however perfect all arrangements may be, their action at the last moment is still dependent upon individual vigilance and presence of mind. It need scarcely be stated that this objection would vanish in the case of dynamo-electric machines, if power were provided for working them continuously as long as any possibility existed of their being required.

The only sources of electricity which at present thoroughly fulfil the conditions essential in the exploding agent to be used with an efficient system of submarine mines, are constant voltaic batteries. By means of the high-tension fuze it became possible to use batteries which were previously inapplicable to the explosion of mines, because, even when employed in considerable numbers, the quantity of electricity furnished by them is not sufficient to effect the ignition of platinum wire-fuzes. Thus, a number of elements of a Daniell's battery, or a sand battery, quite incapable of heating a platinum wire to redness, fires an Abel fuze with perfect certainty. The heat developed in the latter by the passage of a current from such a battery, amply suffices to raise to its igniting point the readily-explosive priming mixture, which serves as the conductor in the fuze. Moreover, the resistance presented by the fuze is so considerable, in comparison with that offered by the longest cables likely to be used in actual practice, that a current from a battery which possesses tension sufficient to overcome the resistance of the fuze, will explode the latter with as much certainty through cables of great length, as when it is close to the battery. A number of cells of a Bunsen battery, of sufficient power to ignite an Abel fuze, and also a fuze of platinum wire several inches long, when close to the battery, will no longer render even a very short piece of thin platinum wire moderately hot, if four or five hundred yards of ordinary conducting wire be

placed in the circuit, while, on the other hand, its power to ignite an Abel fuze will not have become at all affected. It is evident from this illustration that the necessity for greatly adding to battery-power, when mines are to be exploded through considerable lengths of wires, which existed with the use of the wire-fuzes, is obviated by employing a high-tension fuze; and thus one great objection to voltaic batteries, as exploding agents in mining operations, was set aside. Again, the sand batteries, or Daniell batteries, used for telegraphic purposes, which, when once charged, continue, with very little attention, in good working action for several months, could be substituted for the batteries (*e.g.* Grove's or Bunsen's) which it was formerly necessary to employ in order to attain sufficient quantity of current, and which only continue in good action for a few hours. Sand-batteries have been repeatedly employed at Woolwich for the explosion of fuzes, after having been in action four or five months, with the occasional addition of a little water to compensate for evaporation.

It will be thus seen that constant voltaic batteries possess the essential qualifications of efficient exploding agents for use with any system of mines which it is desired to maintain for lengthened periods in a condition ready for explosion at any moment. They are simple of construction, comparatively inexpensive, require but little skill or labour for their arrangement or repair, and very little attention to keep them in constant good working order for long periods, and their action may be made quite independent of any operation to be performed at the last moment.

When first arrangements were devised for the application of electricity in our naval service to the firing of guns, and the explosion of so-called outrigger charges or mines, as originally used in boat attack in the American War, the voltaic pile recommended itself for its simplicity, the readiness with which it could be put together and kept in order by sailors, and the considerable power presented and maintained by it, with very fair constancy, for a number of hours. Different forms of pile were devised at Woolwich for boat- and ship-use, the latter being of sufficient power to fire heavy broadsides by branch circuits, and to continue in a serviceable condition for twenty-four hours, when they could be replaced by fresh batteries, which had in the meantime been cleaned and built up by sailors. The pile for use in boats was of very portable form, and was enclosed in a suitably fitted box to protect it from the weather.

The Daniell- and sand-batteries first used, in conjunction with the phosphide fuze, in the earlier experiments for exploding submarine

mines for purposes of defence, were speedily replaced by a modification of the battery known as Walker's, consisting of one zinc- and two carbon-plates immersed in dilute sulphuric acid. This battery was after some time converted into a modified form of the Leclanché battery, the packed carbon plate being surrounded by a U-shaped zinc plate.

The importance of being able to ascertain by direct electrical tests that the circuits leading to a mine, as well as the fuzes introduced into that circuit for exploding the mine, are in proper order, became manifest when these applications of electricity were quite in their infancy. Many instances are on record in the earlier days of submarine mining of the disappointing results attending the accidental disturbance of electric firing arrangements, when proper means have not been known, or provided, for ascertaining whether the circuit is complete, or for localising any defect when discovered. Thus, during one of the bombardments of Charleston, the United States ironclad "Ironsides" lay for several hours exactly over a large submarine mine containing 3,000 lbs. of gunpowder, which had been placed with great care, but the explosion of which could not be effected, because, as was afterwards discovered, the conducting cable had been severed by the passage of a wagon over it.

It has been pointed out that testing arrangements were to some extent successfully applied in connection with the wire-fuze in the earliest stages of its practical employment. It is scarcely necessary to state that the arrangements for testing all parts of a system of mines, especially in connection with submarine mines for defensive purposes, has some time since been carefully and completely elaborated.

The testing of the high-tension fuze, in which the bridge, or igniting and conducting composition, is composed of a mixture of the copper phosphide and sulphide with potassium chlorate, is easy of accomplishment (by means of feeble currents of high tension), in proportion as the sulphide of copper predominates over the phosphide. Even the most sensitive fuzes, *i.e.*, those containing the highest proportion of phosphide, may be thus tested without fear of exploding them; but when the necessity for a repeated application of tests, or even for the passing of an electric signal through the fuze, arises, as in the case of a permanent system of submarine mines, the case is different; for this particular fuze is susceptible of considerable alterations in conductivity on being frequently, or for long periods, submitted to even very feeble test-currents, and its accidental ignition, by passing through it such

comparatively powerful test- or signal-currents as might have to be employed, becomes then so far possible as to create an uncertainty which is most undesirable.

For this reason, and also because the priming in these fuzes is liable to some chemical change detrimental to its sensitiveness, unless thoroughly protected from access of moisture, another form of high-tension fuze, specially adapted for submarine mining service, was devised at Woolwich. This, though much less sensitive than the original Abel fuze, was quite sufficiently so for service requirements, while it presented great superiority over the latter in stability and uniformity of electric resistance; and, though it was not altogether unaffected by the long-continued transmission of test-currents through it, their action was not found to become detrimental to the efficiency of the fuze. This tension fuze was prepared by compressing a very intimate mixture of graphite and mercury fulminate into a cavity in which the terminals of the fuze very slightly projected; a feeble electric current was passed continuously through the fuze during the operation of pressing, a galvanometer and resistance coil being in circuit, and the compression was continued until the desired resistance, or degree of conductivity, of the fuze was reached. To some comparatively small and variable extent this conductivity fell gradually after the fuzes had been manufactured, but on the whole a remarkable degree of uniformity was attained in their production.

In the employment of these fuzes, which are always used in pairs in a mine, they are carefully selected and classed by testing before actual introduction into the mines.

Although high-tension fuzes presented decided advantages in point of convenience and efficiency over the platinum wire-fuze, as used in the earlier days of electrical firing, the requirements which arose, in elaborating thoroughly efficient permanent systems of defence by submarine mines, and the demand for a form of battery for use in ships which would remain practically constant for long periods, and thus dispense with the necessity for frequent attention to the firing arrangements, caused a very careful consideration of the relative advantages of the high- and low-tension systems of firing to result in favour of the employment of wire-fuzes for these services. The limits placed upon the amount of test- or signal-current which could be passed even through the least sensitive high-tension fuze, and the tendency of the latter to alter in conductivity when submitted to the action of those currents for long periods, were considerations decidedly in favour of the conclusion arrived at. In addition to these, there was an element

of uncertainty, or possible danger, in the employment of high-tension fuzes, which, though in part eliminated by the employment of voltaic batteries, in place of generators of high-tension electricity, might still occasionally constitute a source of danger, namely, the possible liability of high-tension fuzes to be accidentally exploded by currents induced in cables, with which they were connected, during the occurrence of thunder-storms, or of less violent atmospheric disturbances.

It has been amply demonstrated by experiment, and by results obtained in military operations, that if insulated wires, immersed in water, buried in the earth, or even extended on the ground, are in sufficient proximity to one another, each cable being in circuit with a high-tension fuze and the earth, the explosion of any of the fuzes by a charge from a Leyden jar, or from a dynamo-electric machine of considerable power, may be attended with the simultaneous ignition of the fuzes attached to adjacent cables, which are not connected with the source of electricity, but which become charged by the inductive action of the transmitted current to a sufficient extent to produce this result. Such being the case, it appears very possible that insulated cables extending to land or submarine mines, in which high-tension fuzes are enclosed, may become charged inductively during violent atmospheric electrical disturbances to such an extent as to lead to the accidental explosion of such mines. Mr. Preece, in an interesting Paper on underground telegraphs which he contributed to the Society of Telegraph Engineers, gives an instance of the inductive effects of lightning discharges upon underground cables enclosed in pipes, the persons engaged in the operation of jointing the wires during a storm having seen sparks pass between the bare joint of the wires and the joint-box against which they were resting, and other eminent electricians confirmed from personal experiences that which he quoted. Although the lengths of cables used in mining operations are quite insignificant when compared with the shortest telegraph cables to which the observations of those gentlemen refer, the sensitiveness of high-tension fuzes to ignition fully justified the doubts entertained whether their use might not be attended by a possibility of serious risk of accident, or at any rate of the unintentional explosion of mines placed in position for purposes of defence, especially in climates where very violent electrical disturbances are of frequent occurrence. Apprehensions of this nature were entertained by Von Ebner, and in a Report by that officer on the defence of Venice, Pola, and Lissa, by submarine mines, in 1866, he refers to the accidental

explosion of one of a group of sixteen mines during a heavy thunderstorm, as well as to the explosion of some mines in the harbour of Pola, by the direct charging of the cables, through the firing station having been struck by lightning. It was to avoid such accidental explosions that he devised an ingenious but complicated circuit-closing arrangement, to be applied in the submarine mines themselves, by the employment of which the fuzes in the mine were only brought into connection with the cable leading to the firing stations when the mine was struck by a passing ship.

Two instances of the accidental explosion of tension fuzes by the direct charging of overhead wires during lightning discharges occurred in 1873 at Woolwich, and a fuze connected with an overhead insulated wire at Chatham was also exploded accidentally in the same year, though whether by an induced charge or by the direct action of a lightning discharge was not conclusively demonstrated. Subsequently an electric cable was laid out at Woolwich along the river bank below low-water mark, and a tension fuze was attached to one extremity, the other being buried. About eleven months afterwards the fuze was exploded by a charge induced in the conductor during a very heavy thunderstorm.

In consequence of the difficulties experienced in the special application of the high-tension fuzes to submarine purposes, arising out of the circumstances just alluded to, the production of comparatively sensitive low-tension fuzes, of much greater uniformity of resistance than those employed in former years, was made the subject of an elaborate experimental investigation by the lecturer, in the course of which several points of interest and of value in the subsequent application of the results were arrived at. Experiments instituted with platinum wires, much finer than those hitherto used in the construction of fuzes, demonstrated that wires made of different specimens of commercial platinum varied very greatly in electrical conductivity. As these variations might be due to two causes, or combinations of them, namely, a difference in the purity and in the physical condition of the metal, the matter was investigated in both directions. It was found that very considerable differences in the amount of forging to which the metal, in the form of sponge had been subjected, did not affect to any important extent either its specific gravity or its conductivity, and that the fused metal had only a very slightly higher degree of conductivity than the same sample forged from the sponge. It was therefore clearly established that the conductivity of such very fine wires as it was proposed to use in the construction of

fuzes was but slightly affected by physical peculiarities of the metal of which they were composed, and that the considerable differences in conductivity observed in different samples of platinum were ascribable to variations in the degree of purity of the metal. As it appeared likely, therefore, that more uniform results would be attained by the employment of some alloy of definite and uniform composition as the bridge for low-tension fuzes than by the use of commercial platinum, varying considerably in composition, experiments were made with fine wires of German silver (which had been used by a well-known American electrician, Mr. Farmer, in the construction of comparatively sensitive wire fuzes), and of the alloy of 66 of silver with 33 of platinum employed by Matthiessen for the reproduction of B. A. Standards of electrical resistance. It was found that both these alloys were greatly superior to ordinary platinum in regard to the resistance opposed to the passage of a current, and the heat consequently developed in given lengths of wire of a particular diameter, and that German silver was in its turn superior in this respect to the platinum silver alloy; although the difference was only trifling in the small lengths of fine wire used in a fuze (0·25 inch). On the other hand, the comparatively ready fusibility of a platinum-silver wire contributed, with other physical peculiarities of the two alloys, to reduce fine German silver wire to about a level with it. Moreover, German silver was found not to resist the tendency to corrosive action exhibited by gunpowder and other more sensitive explosive agents, which have to be placed in close contact with the wire-bridge in the construction of a fuze, so that the latter may be at once fired when the required heat has been developed by the resistance which the wire-bridge offers to the current; platinum-silver on the other hand was found to remain unaltered under corresponding conditions of exposure.

The superiority of platinum-silver, and even German silver, as a material for the bridges of fuzes appeared, therefore, to be established from a practical point of view; but, as some difficulties were apprehended by the manufacturers in the uniform production of a silver alloy containing the large proportion of platinum essential to furnish the high-resistance wire required, experiments were made with alloys of platinum with definite proportions of iridium, the metal with which it is chiefly associated, and eventually very fine wires of an alloy containing 10 per cent. of iridium were selected as decidedly the best materials for the production of wire-fuzes of comparatively and very uniform high resistance, this alloy being found decidedly superior in the latter respect,

as well as in point of strength (and therefore of managableness in the state of very fine wire, 0·001 in. in diameter), to the platinum-silver wire. The fuzes now used in military and submarine service are therefore made with bridges of iridio-platinum wire, containing 10 per cent. of the first-named metal; the wire-bridge in the fuzes for submarine mining services, which are fired by means of Leclanché batteries, being somewhat thicker and therefore of higher conductivity than those used for land-service, which are exploded by low-tension dynamo-electric machines manufactured by Siemens Brothers.

The electrical gun-tubes used in the navy are fired by means of a Leclanché battery specially devised for the purpose, and the circuits to the different guns are arranged in branch; when broadside firing is required, it is important that the wire-bridge of any one of the gun-tubes which is first fired should be instantaneously fused on the passage of the current, so as to cut this branch out of circuit; in this respect it was believed that the platinum-silver alloy, being much more fusible than iridio-platinum, presented an advantage, and hence the naval electrical fuzes are made with bridges of that alloy; there is, however, no reason to believe that the finest wire of iridio-platinum is not quite as efficient for this particular service. Uniformity of electrical resistance has become a matter of such high importance in the delicate arrangements connected with our system of submarine mines, as now perfected, that the very greatest care is bestowed upon the manufacture of service electric fuzes or detonators, which are in fact made, in all their details, with almost the precision bestowed upon delicate scientific instruments, and the successful production of which involved an attention to minutiæ which would surprise a superficial observer. Even the manner in which the wire-bridge had to be surrounded by a readily-ignitable preparation to communicate fire to the charge of powder or mercury fulminate, in the fuze, involved much thought and experiment. The sensitiveness of the fuzes as now manufactured is very uniform, while the manufacturing limits of variation in electrical resistance are very small.

It has been stated that the batteries used for exploding these sensitive wire fuzes and detonators are varieties of the Leclanché, into which improvements have been introduced from time to time. It is very possible, now that dynamo-electric machines are applied to illuminating purposes in our large ships of war, and that the electric light is used for signalling and tactical purposes at the submarine mining stations of our naval ports,

that the explosion of mines and the firing of guns by dynamo-electric agency may also be provided for, in time to come, as there would be no difficulty in providing the power for working these continuously, whenever they were likely to be called into use.

The applications of electricity to the explosion of gunpowder are so numerous and important that it is only possible within the limits of this Lecture to give an outline of some of the more interesting and prominent.

One of the earliest of these was the firing of guns upon proof at Woolwich by the voltaic battery, which was very efficiently carried out as far back as 1854 by Sergeant McKinlay, the proof master, who employed a Grove battery and constructed a very neat gun tube, which was fired by a platinum-wire bridge, surrounded by gunpowder in a small cup fixed on the top of the tube, the wire bridge being soldered to two small copper tubes or eyes, which passed through the cup and served to receive the terminals of the battery, an arrangement which was applied in various forms of electric tubes and fuzes afterwards devised. The current was successively directed into the individual circuits connected with the guns to be proved at one time by means of a simple shunt-apparatus. Before the employment of this arrangement, the proof of guns was more than once attended by casualty, consequent upon the uncertain nature of the appliances which had to be adopted in firing the guns by means of a species of time-fuze. When the high-tension phosphide electric fuze had been devised, gun tubes were made to which it was applied, and after the proof operations had been carried out for some time by their means, with the use of Henley's large magneto-electric machine, an exploder was arranged by Wheatstone, which was provided with a large number of shunts, so that as many as twenty-four guns might be brought into connection with the instrument in rapid succession, and fired by the depression of separate keys connected with each. This method of firing has continued in use up to the present time, and Wheatstone's magneto-electric exploders have, moreover, performed good service at Woolwich and Shoeburyness during the last twenty-eight years, being used for the firing of guns, by means of the Abel gun-tubes, in all experiments connected with artillery-, armour-plate- and gunpowder investigations.

The firing of cannon as time-signals is an ancient practice in garrison towns, but the regulation of the time of firing the gun, an electrical agency from a distance, appears first to have been accomplished in Edinburgh, where, since 1861, the time-gun has

been fired by a mechanical arrangement, actuated by a clock, the time of which is controlled electrically by the mean-time clock at the Royal Observatory on Calton Hill.

Shortly after the establishment of the Edinburgh time-gun, others were introduced at Newcastle, Sunderland, Shields, Glasgow, and Greenock. The firing of the gun was arranged for in various ways; in some instances it was effected either direct from the observatory at Edinburgh, or from shorter distances, by means of Wheatstone's magneto-electric exploders. Some of these guns were discontinued, but at the present time there are time-guns at West Hartlepool, Swansea, Tynemouth, Kendal, and Aldershot, which are fired electrically, either by currents direct from London, or by local batteries, which are thrown into circuit at the right moment by means of relays, controlled from St. Martins-le-Grand. The high-tension fuze, in the form of gun-tubes, is chiefly applied to these services.

It has already been pointed out, in tracing the successive changes in the nature of electric fuzes, how, about thirteen years ago, the electrical firing of guns, especially for broadsides, was first introduced into the Navy, with the employment of the Abel high-tension gun-tube and voltaic piles. The gun-tubes, originally manufactured at the Woolwich Laboratory simply for the proof of cannon and for experimental artillery operations, and which were of very simple and cheap construction, were in the first instance adopted for use in the Navy, for the instantaneous firing of guns, and were obviously, as experience proved, unfitted to withstand exposure to the very various climatic influences which they had to encounter in Her Majesty's ships, and in store in different parts of the world. They therefore were naturally found to deteriorate, and to have become unserviceable on several occasions, a result which was somewhat hastily ascribed entirely to the changeable nature of the priming composition with which these fuzes were prepared. Unquestionably, however, the low-tension gun-tubes, having a bridge of very fine platinum-silver wire, surrounded by readily ignitable priming composition, are much more suited to our naval requirements than the comparatively very sensitive high-tension fuze.

The arrangements in Her Majesty's ships for firing broadsides electrically, and also for the electrical firing of guns in turret-ships, have been very carefully and successfully elaborated in every detail, including the provision of a so-called drill- or dummy electrical gun-tube (which is used for practice and refitted by well-instructed sailors), the careful testing and balancing of

the gun-tubes, examination of the gun-circuits, &c.; and the guns may be fired either simultaneously from the conning tower on deck, or independently. For gun-firing, ships are supplied with a set of six very large Leclanché cells, arranged in series, a stout zinc plate being on either side of the packed carbon element, which is built of four gas-carbon plates attached to one common bridge The ebonite trough, containing the plates, &c., measures 16 inches in length, and is 9 inches deep by $2\frac{3}{4}$ inches wide. The object of these large cells is to obtain a considerable quantity of electricity with as few elements as possible, thus reducing the loss of power which occurs when a large number of separate cells are connected up. The power of this battery-force is maintained for a long period in excess of the work it has to perform. A very portable arrangement of the Menotti form of Daniell battery, fitted with a galvanometer, is provided for testing batteries, &c., both for ship- and boat-service. The firing-keys, and all other arrangements connected with electrical gun-firing, are specially designed to ensure safety and efficiency at the right moment.

The battery supplied for the firing of outrigger torpedoes, and for other operations to be performed from open boats, consists of a portable arrangement of three smaller cells of the Leclanché battery (the carbon element fitting into a U-shaped zinc plate) enclosed in a box, which is fitted externally with connecting screws, and a firing-key, with safety arrangement to guard against its acting accidentally, and a strap to pass over the operator's shoulders, so that he has the instrument quite at his command in front of him. The electric detonators used with this battery correspond, so far as the bridge is concerned, with the naval electric gun tubes.

These electric appliances are now distributed throughout the navy, and the men are kept, by instruction and periodical practice, well versed in their use.

The subject of the application of electricity to the explosion of submarine mines, for purposes of defence and attack, received some attention from the Russians during the Crimean War under the direction of Jacobi; thus a torpedo, arranged to be exploded electrically when coming into collision with a vessel, was discovered at Yeni-Kale, during the Kertsch expedition in 1855. Some arrangements were made by us, at the conclusion of the war, to apply electricity to the explosion of large powder charges enclosed in huge cylinders of boiler-plate, for the removal of sunken ships in Sevastopol Harbour, and of a large submarine obstruction of stone which the Russians had placed at the north entrance to Cronstadt Harbour; but they were not used. Torpedo defence, in its most

simple form, was first applied by the Austrian Government in 1859, when a system of submarine mines, to be fired through the agency of electricity by operators on shore, was arranged by Von Ebner for the defence of Venice, which, however, never came into practical operation. Early in 1860 Henley's large magneto-electric machine, with a supply of Abel fuzes, and stout india-rubber bags with fittings to resist water-pressure, were dispatched to China, for use in the Peiho River, but no application appears to have been made of them. The subject of the utilization of electricity for purposes of defence did, however, not receive systematic investigation in England or other countries until some years afterwards, when the great importance of submarine mines as engines of war was demonstrated by the number of ships destroyed and injured during the war in America. Twenty-five vessels belonging to the Federal navy were destroyed, and nine others injured, by the explosion of mines and torpedoes, while the Confederates lost three vessels by accidentally coming into collision with their own mines, and one which was attacked by means of a torpedo and destroyed by the Federals. In only two of these cases of destruction, however, were the explosions accomplished by electrical agency; in all the others, the mines were exploded by mechanical means. One instance of the effective power of a well-planned submarine mine may be selected from the experiences of the American Civil War, as an illustration of the formidable nature of this method of defence. The important defence of the water-approach to Richmond was entrusted to a single electric mine of considerable power, sunk in the channel-way of James River. This mine was under the control of an officer who, stationed on one of the river banks, watched, from the sand-pit where he lay concealed, the approach of the enemy. A single stake planted upon the opposite bank served to indicate, by the passing vessel being in a line with his station and the stake, the exact moment when she would be within the area of destruction. With the patience of a spider watching for its victim, so for thirteen months did this officer remain, waiting for the opportunity to explode the mine with effect. At length the Federal fleet, under the command of Commodore Lee, entered the James River—the commodore's vessel being the third in the advancing rank. The foremost vessel, carrying seven guns, and manned with a picked crew of one-hundred and twenty-seven men, was allowed to pass over the mine in safety (it being by arrangement held in reserve for the commodore's ship), when, the order having been passed from the deck of the next vessel, and audible on shore, for her to fall back

and drag for torpedo-wires, the officer determined to explode his mine, and "hoist" her as she descended the stream. The explosion took place on a clear afternoon, and was witnessed by several persons; the hull of the vessel was visibly lifted out of the water, her boilers exploded, the smoke-stacks were carried away, and the crew projected into the air with great velocity; out of the hundred and twenty-seven men only three escaped alive. The awfully sudden and unexpected destruction of this vessel paralysed the operations of the Federal fleet for a time, and Richmond was saved; Commodore Lee, declining to advance, sunk several of his ships, blocking up the channel way. This obstruction afterwards, on the advance of General Butler, gave rise to the cutting of the "Dutch Gap" canal, now a matter of history.

Soon after the commencement of that war, the attention of the English Government was called to the importance of practical inquiry into the value of submarine obstructions, both passive and active, as auxiliary agents of defence, and a Government Committee was appointed, in 1863, to report on the use which might be made of floating or sunken obstructions, and of submarine mines, in the defence of channels, harbours, and rivers. This Committee was enabled, by the aid of systematic investigations conducted for them at Woolwich during the following four years by one of their members, Mr. Abel, and of practical experiments carried on chiefly at Chatham under the direction of another of their body, the late Colonel A. à'C. Fisher, C.B., R.E., to elaborate the subject of the application of electricity to submarine mines and torpedoes, to such an extent that a solid foundation of information was prepared for the several committees, appointed by the War Office and the Admiralty, who afterwards pursued different branches of the subject to the practical issues which were attained now some years since. It was towards the close of the labours of the so-called Floating Obstructions Committee (in 1867) that the School of Submarine Mining at Chatham, and the Naval Torpedo-School at Portsmouth were developed, the foundation of the latter having been laid at the Chemical Department, Woolwich. Some continental Governments also devoted attention to the subject of the application of electricity to submarine mines at about this time, and more especially the Austrian Government, for whom Baron von Ebner, who had already applied submarine mines to the defence of the harbour-entrance of Malamocco in 1859, devised an ingenious and elaborate system of electric torpedo defence, for employment in conjunction with his high-tension fuzes, which was applied to the defence of Venice, Pola, and Lissa during the

war of 1866, though its efficiency was not put to any actual test, except by way of experiment.

The application of electricity to the explosion of torpedoes was, as stated, very limited during the American war, but arrangements for the extensive employment of that agent as the exploding power were far advanced in the hands of both the Federals and Confederates at the close of that war, men of very high qualifications, such as Captain Maury, Mr. N. J. Holmes, and Captain McEvoy having worked arduously and successfully at the subject.

The explosion of submerged charges of gunpowder by mechanical contrivances, either of a self-acting nature or to be set into action at desired periods, was accomplished as far back as 1583, during the siege of Antwerp by the Duke of Parma. The English employed self-acting torpedoes against the French ships off Rochelle in 1628, and from that period to 1854, devices of more or less ingenious and practicable character have been proposed from time to time, and even applied, to some small extent, in different countries, for the explosion of torpedoes either by clockwork at fixed periods, or by coming into collision with a ship. The Russians were the first to apply self-acting mechanical torpedoes with any prospect of success, and there is little doubt that, had the machines used for the defence of the Baltic been of larger size (they only contained 8 or 9 lb. of gunpowder), their presence would have proved very disastrous to some of the English ships which came into collision with and exploded them. Various mechanical devices for effecting the explosion of torpedoes by their collision with a ship were employed by the Americans, a few of which proved very effective. But although, in point of simplicity and cost, a system of defence by means of mechanical torpedoes possesses decided advantages over any extensive arrangements for exploding submarine mines by electric agency, their employment is attended by such considerable risk of accident to those at whose hands they receive application that, under many circumstances which are likely to occur, they become almost as great a source of danger to friend as to foe. Thus the operations of lowering and mooring the mine, the explosion of which depends upon the application of a blow, thrust, or pull to some portion of the machine which is so placed and arranged as to be in a favourable position for the application of mechanical action by a passing ship, are attended with very great danger to those employed, unless some means are adopted for rendering the exploding mechanism inactive until after the torpedo has been placed in

position. But the employment of a safeguard of this kind involves a considerable amount of uncertainty as to the torpedo being rendered active after the operation of mooring is completed, because the very removal of the safeguard is frequently a dangerous operation. Again, when once self-acting mechanical mines have been placed in position and rendered active, they are as dangerous to friendly ships as to the enemy; consequently their employment for the defence of a particular tract of water completely closes it until they have been exploded or removed, and their removal obviously constitutes one of the most dangerous services on which men can be employed. Several instances occurred in America, some years after the termination of the war, of the destruction of ships in waters which had been defended by mechanical mines, the subsequent removal of which was thought to have been completely accomplished. Some improvements have recently been made in mechanical and chemical appliances of a self-acting nature for submarine mines, by the employment of which the mooring arrangements can be completed in perfect safety, and the torpedoes afterwards rendered active, by the performance of a simple and perfectly safe operation, when it is desired to close the defended water. But the complete exclusion of friendly vessels, and the difficulties attending the raising of self-acting mechanical mines when no longer required, still constitute formidable objections against their use, excepting in the case of tracts of water which are not ordinarily navigated, but the passage of which in times of war might be attempted by vessels of light draught. The most successful results yet obtained in this direction has been by a combination of mechanical with self-contained electrical arrangements which have been devised by Mr. Matheson and others.

The most important advantages secured by the application of electricity as an exploding agent of submarine mines are as follows: they may be placed in position with absolute safety to the operators, and rendered active or passive at any moment from the shore; the waters which they are employed to defend are therefore never closed to friendly vessels until immediately before the approach of an enemy; they can be fixed at any depth beneath the surface (while mechanical torpedoes must be situated directly or nearly in the path of a passing ship), a circumstance which very considerably simplifies the arrangements for their application in tidal waters; lastly, electric mines may, when no longer required, be removed with as much safety as attended their application.

There are two distinct systems of applying electricity to the

explosion of submarine mines. The most simple is that in which the explosion is made dependent upon the completion of the electric circuit by operators stationed at one or more posts of observation on shore. The particular mode of arrangement, and the operation to be adopted, depend in great measure on the nature of the locality to be defended. If this be a river or channel the plan of arranging and exploding mines is comparatively simple, but will serve sufficiently to illustrate the general nature of this system of applying torpedoes. The mines are arranged across the river or channel in rows or lines, converging towards a station on shore to which the conducting cables are led which are to connect each mine with the exploding instrument. The operator at this station has it in his power, therefore, to explode any one of the mines at will, by completion of the circuit through the particular cable and the earth. Some other position on shore is selected as a second station, which commands points of view intersecting the lines of mines. The operators at the two stations are placed in telegraphic communication with each other, and when a ship is observed by the operator at the second station to approach in the direction of any one of the mines, he will signal to the man who looks along this line, and the latter will complete circuit as soon as the vessel appears over the particular mine specified. Should the vessel alter her course in approaching the mine, the operator at the observing station will inform the man at the firing station, who will alter his arrangements accordingly. Or the man at the observing station, when he perceives a vessel to approach in a line with any of the mines, places the cable of that mine in electric connection with the operator at the other station, and the latter will complete the circuit through the earth as soon as he sees that the vessel is over the first line of mines. Other more or less elaborate modifications of these modes of observing and exploding have been proposed; they all depend for efficiency on the experience, harmonious action, and constant vigilance of the operators at the exploding and observing stations. They are, moreover, entirely useless at night, and in any but clear weather. Mines arranged solely for firing by observation are therefore not to be compared in general efficiency to self-acting mines, which are either exploded by their collision with a ship, whereby electric circuit is completed within them, or by the vessel striking a circuit-closing arrangement moored near the surface of the water, whereupon either the mine, moored at some depth beneath, is instantly exploded, or a signal is furnished at the station on shore which indicates to an operator the particular mine to

be exploded. The object to be attained in these circuit-closing apparatus, which are so moored as to be within range of a passing ship, is to oppose in the path of a vessel a contrivance which will not be affected by the motion of the water, but which will complete electric circuit between the conducting cable and the fuze, or will bring a relay into operation which throws the fuze into circuit with the firing battery if the circuit closer be struck in some particular part, or thrown into a particular position by the advancing ship. Many ingenious contrivances have been devised for this purpose and experimented with, but only a few have furnished satisfactory results, the conditions essential to success being numerous, and their combined fulfilment not easy of attainment. Simplicity of mechanism, and a combination of sufficient, but not excessive, delicacy of action, with permanence during long immersion, are among the most important objects to be aimed at in the construction of these circuit-closing or signalling machines, or self-acting mines.

One of the earliest circuit-closers with which any measure of success was obtained was devised by the Lecturer in 1864, and extensively experimented with by successive Committees at Chatham; though efficient of its class it was decidedly inferior to circuit-closers of which the entire mechanism is enclosed and therefore protected from injury. Of this class the first really efficient one was that devised by Mr. Matheson (late Quartermaster-Sergeant, R.E.), which was adopted into the Service some years ago, and was gradually modified and improved until the present English Service circuit-closer was produced.

Such are the general principles of the arrangements adopted in connection with the application of electricity to the explosion of submarine mines; it would be beyond the scope of this lecture to enter into details respecting the numerous arrangements and appliances connected with a system of defence by submarine mines, such as is now ready for application at any time at our several naval ports at home and abroad, and the utilization of which has already been actively taken up by our colonies.

Continental nations have followed in our footsteps, in providing themselves with equipments for defensive purposes by submarine mines, and our Scandinavian friends, the Danes, Swedes, and Norwegians, have pursued the subject of submarine mines with special activity and success. Experiments, vying with our own in extent and importance, have been instituted by them on the effects of submarine explosions, and the relative merits of different systems of mines and auxiliary arrangements, some very simple

and efficient circuit-closers and other appliances having been elaborated by them.

In England, while we are fortunate in having eminent electric engineers and mechanicians like Captain McEvoy and Mr. Matheson, always active in developing improvements in the science of submarine warfare, our corps of Royal Engineers must be congratulated upon the unceasing activity and success with which many of their most talented officers have laboured at the continual improvement of our armament for submarine mining service, and upon the zeal with which they endeavour to make every important advance in applied electrical science contribute to increase the completeness of our arrangements for submarine electric operations of defence and offence, and of our control over those arrangements. That endeavours are made to utilize in this direction every important advance in electrical science and in the practical results emanating therefrom, is illustrated by the important uses already made of the electric light in connection with submarine mining service, and by promising results obtained in the application of accumulative batteries as the signalling batteries for mines, in the employment of the microphone for detecting the approach of ships to a submarine mine station, in the use of Hughes' induction balance as a means of searching for submerged mines, &c.

In the United States, where the first great impetus was given to the utilization of electricity as an exploding agent for war purposes, the subject has continued to be actively pursued, and important improvements in exploding instruments, electric fuzes, and other appliances have been made from time to time by Smith, Farmer, Hill, Striedinger, and others already mentioned. But no individual has contributed more importantly to the development of the service of submarine explosions than General Abbot, of the United States Engineers. That officer has been for years past engaged upon valuable work connected with the application of electricity to explosions, and the scientific and practical elaboration of the conditions to be fulfilled in the successful accomplishment of simultaneous explosions upon a large scale; the value of the work performed by him in this direction was demonstrated by the remarkable success of by far the most gigantic operation of electric explosion which has been accomplished, to which further reference will presently be made. In an official report upon investigations to develop a system of submarine mines for defending the harbours of the United States, printed in 1881, General Abbot includes an account of a most valuable series of experimental and theoretical investigations of the physical phenomena and force developed by

submarine explosions with all the most prominent explosive mixtures and compounds, and of the properties and relative merits of the various high-, medium-, and low-tension fuzes, and of every class of electrical igniting apparatus. This work is rich in original and important observations and deductions, and well illustrates the very comprehensive nature of the science of submarine mining.

Illustrations of actual results capable of being produced in warfare, by the application of electricity to submarine operations, have hitherto been very few; but of the moral effects of submarine mines we have already had abundant proof. In the war which was carried on for six years by the Empire of Brazil and the Republic of Paraguay, the latter managed, by means of submarine mines, to keep at bay for the whole period the Brazilian fleet of fifteen ironclads and sixty other men-of-war. The means available for applying electricity to the explosion of these mines were limited; a large proportion of the three hundred that were laid down were therefore arranged for explosion by mechanical means. In the Russo-Turkish war, submarine mines and torpedoes were a source of continued apprehension, and it is well known that the French naval superiority was paralysed, during the Franco-German war, by the existence, or reputed existence, of mines in the Elbe.

The application of electricity to the explosion of military mines, and to the demolition of works and buildings, from a safe distance, has, it need hardly be stated, been of great importance in recent wars in expediting and facilitating the work of the military engineer. The rapidity with which guns, carriages, &c., were disabled and destroyed by a small party of men who landed after the silencing of the forts at Alexandria furnished an excellent illustration of the advantages of electrical exploding arrangements, combined with the great facility afforded for rapid operation by the power possessed of developing the most violent action of gun-cotton, dynamite, &c., through the agency of a detonation without any necessity for confining or tamping the charge.

The application of electricity to the explosion of mines for land-defences during active war is by no means an easy operation, inasmuch as not only the preparation of the mines, but also the concealment of electric cables and all appliances from the enemy, entails great difficulties, unless circumstances have permitted, or have appeared to render it prudent to make, the necessary arrangements in ample time to prevent a knowledge of them reaching the enemy. An elaborate system had been devised for defending the

chief approaches to Paris in this way in 1870, but no preparations were attempted until it was impracticable to render this system of defence available.

Turning from military and naval applications of electricity to explosive purposes, but few words need be said to recall to the minds of civil engineers the facilities which the employment of electricity as an exploding agent affords for expediting the carrying out of many kinds of work in which they are immediately interested. Electrical blasting, especially when used in combination with rock-boring machines, has revolutionised the operations of tunnelling and driving of galleries; and, although in ordinary mining and quarrying operations, the additional cost involved in the employment of fuzes and conductors, and the original price of the exploding machine, are not unfrequently of serious consideration, there are, even in those directions, many occasions when the power of firing a number of shots simultaneously is of very great importance. There is little doubt, moreover, that accidents in mining and quarrying would be considerably reduced in number, if electrical blasting were more frequently employed, especially in dangerous mines, instead of the comparatively uncertain system of firing by slow-burning fuze. Many men meet their doom through going up to a shot hole in the false belief that the fuze has burned out, or become extinguished. With electric firing the simplest precautions suffice to ensure absolute safety.

A substitute for electrical firing, which possesses considerable merit, and which has been applied with success to the practically simultaneous firing of several charges, claims a passing notice here. It is a simple modification of the Bickford fuze, which, instead of burning slowly, flashes rapidly into flame throughout its length, and hence has received the name of instantaneous fuze, the earliest form having been brought from America under the name of lightning fuze. The fuze, as manufactured by Messrs. Bickford, Smith, and Co., burns at the rate of about 100 feet per second; it has the general external characteristics and flexibility of the ordinary mining fuze, but is distinguished from the latter by a coloured external coating. Numerous lengths of this fuze can be coupled up together in a simple manner, so as to form branches leading to different mines or shot holes, which may be ignited together, so as to fire the holes almost simultaneously. In the navy this fuze is used as a means of firing small gun-cotton charges which may be thrown by hand into boats when these engage each other, the fuze being fired from the attacking boat by means of a small pistol, into the barrel of which the extremity

is inserted. In hurried attacks of this nature it would be difficult to deal with wires and electrical exploders.

The conveniences presented by electric-firing arrangements, under special circumstances, are interestingly illustrated by a novel proceeding at the launch of a large screw steamer at Kinghorn, in Scotland, about a year ago. This launch was accomplished by placing small charges of dynamite in the wedge blocks along the sides of the keel, and exploding them in pairs, one on each side of the vessel, hydraulic power being applied at the moment that the last wedges were shot away.

In the deepening of harbours and rivers, and the removal of natural or artificial submerged obstructions, the advantages of electric-firing are so obvious that it is only necessary to refer to them, but this account of the application of electricity as an exploding agent cannot be better concluded than by a brief recital of the most extensive operation of the above kind which has hitherto been carried out, namely, the destruction of the reef of Hallett's Point[1] (Hell Gate) in East River, New York, in September 1876. The area of rock operated upon, which included all that portion of the reef within the curve of 26 feet below mean low-water, was 3 acres. This space was perforated with forty-one radial tunnels, long and short, and with eleven transverse galleries, leaving as supports to the roof one hundred and seventy-two piers. The aggregate length of tunnels and galleries was 742,567 feet; the amount of rock which had been excavated from these was 49,480 cubic yards; and the time consumed in this work was four years and four months. The work of drilling charge-holes was commenced in June 1875, and at its completion, in March 1876, five thousand three hundred and seventy-five 3-inch holes had been drilled in the roofs, and in the piers one-thousand and eighty 3-inch, and two hundred and eighty-six 2-inch holes; the total length of holes drilled being 58,445 feet. In the earlier portion of the work of excavation powder was used for blasting, but from June 1872 machine-drills and violent explosives were gradually brought into use. Dittmarr's preparation of nitrated sawdust and nitro-glycerine, known as dualin, and nitro-glycerine alone, manufactured by Mr. Mowbray, were employed experimentally in the earlier operations. In the concluding demolition the explosives used were giant powder, or No. 1 dynamite; rendrock (the name adopted in America for litho-fracteur); and Vulcan powder, or Vigorite, another nitro-glycerine preparation, which is a mixture

[1] Minutes of Proceedings Inst. C.E., vol. l., p. 292: liii., p. 397.

of nitrate of soda, sulphur, and charcoal, with about 30 per cent. of nitro-glycerine. A total of 49,914 lbs. of these explosives was used in the single operation. The number of holes charged with these was four thousand four hundred and twenty-seven. The operation of charging occupied nine days. The detonating electric fuzes, charged with mercury fulminate, were contained in priming charges weighing $\frac{3}{4}$ lb. each, enclosed in brass tubes; these were inserted over the charges, which were enclosed in tin cases hermetically closed to exclude access of water. Very simple and effectual means were used for fixing the cases in the holes in the roofs of the galleries, &c. The charges were connected in continuous series in groups of twenty, and these again were arranged in divided circuit in eight groups, every group being connected with a distinct carbon zinc battery of forty to forty-four cells. Each battery was thus arranged to explode one hundred and sixty charges. The simultaneous explosion of the complete system of mines was accomplished by a simple circuit-closer, governing the whole of the twenty-three series of charges, which was devised by Julius Striedinger, C.E., who rendered important services in connection with the electrical arrangements.

All was completed by the 23rd of September, 1876. Water was admitted to the excavations, which were filled to the level of the tide in seven and a half hours, and the simultaneous explosion of the charges was effected on the following day. The maximum height to which spray was projected by the explosion was 123 feet, the volume of water raised being comparatively trifling, as was also the shock of the explosion. Advantage was taken of this stupendous operation to make observations on the rate of transmission through the earth's crust of an artificially produced impulse analogous to an earthquake; and this work was entrusted to General Abbot, who worked out the formulæ regulating the arrangements of the batteries, fuzes, and circuits by which the operations were brought to a successful issue. The total amount of rock demolished by the explosion was 63,135 cubic yards. As an illustration of the electric simultaneous explosion of charges, this operation still remains without a parallel, and, though it was obviously impossible to ascertain whether the whole, or what proportion, of the charges had exploded, there appears little doubt, from the completeness of the demolition, that the operation was practically successful over the whole area operated upon. Mr. Striedinger's circuit-closer consisted simply, on the one hand, of a fixed wooden plate or slab fitted with a number of mercury-cups corresponding to the number of firing circuits, one of the wires

from each of which being attached to the cups below the plate that supported them; and, on the other hand, of a similar movable plate placed vertically over the fixed plate, and carrying a number of brass pins, corresponding to the mercury cups, and connected with the other branches of the circuit. The latter plate was suspended immediately over the fixed one by a cord, into which a small cartridge was introduced; the explosion of this by an independent battery severed the cord, and allowed the pins to enter the mercury-cups simultaneously.

The outline which has been given of this branch of applied electricity, though unavoidably superficial, will, it is hoped, have conveyed some idea of its history, development and importance, and have also in some measure served to substantiate its claim to rank, if only the last, among the great illustrations which have been brought before you in this course, of the practical benefits resulting from the patient study of science.

Sir JOSEPH BAZALGETTE, Vice-President, said: Gentlemen, you have already anticipated the proposal that I have to make to you. I think you will agree with me that if Sir Frederick Abel had not received the honour of knighthood, his lecture to-night would have entitled him to that honour. Although I must confess that some parts of the lecture, and some of the apparatus with which we have been surrounded, have been a little trying to an ordinary civilian like myself, I am sure you will agree with me in offering hearty good wishes to Dr. Siemens and Professor Abel, who are to go to-morrow to Osborne to receive those honours which they have so well earned.

Sir FREDERICK ABEL: Allow me to say one word. I thank you, sir, most heartily, and my audience, for the kind manner in which they have received my discourse. I would only ask to be allowed to transfer a large portion of your thanks to Mr. Brown and my other friends who have kindly assisted me in the preparation of the experiments.

3 May, 1883.

JAMES BRUNLEES, F.R.S.E, President,
in the Chair.

Electrical Units of Measurement.

By Sir WILLIAM THOMSON, F.R.S., M. Inst. C.E.

IN physical science a first essential step in the direction of learning any subject, is to find principles of numerical reckoning, and methods for practicably measuring, some quality connected with it. I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind: it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of *science*, whatever the matter may be. I may illustrate by a case in which this first step has not been taken. The hardness of different solids, as precious stones and metals, is reckoned by a merely comparative test. Diamond cuts ruby, ruby cuts quartz, quartz, I believe, cuts glass-hard steel, and glass-hard steel cuts glass; hence diamond is reckoned harder than ruby; ruby, than quartz; quartz, than glass-hard steel; and glass-hard steel, than glass: but we have no numerical measure of the hardness of these, or of any other solids. We have, indeed, no knowledge of the moduluses of rigidity, or of the tensile strength, of almost any of the gems or minerals, of which the hardness is reckoned by mineralogists in their comparative scale, beginning with diamond, the hardest of known solids. We have even no reason to believe, that the modulus of rigidity of diamond is greater than that of other solids; and we have no exact understanding of what this property of hardness is, nor of how it is related to moduluses of elasticity, or to tensile or shearing strength, or to the quality of the substance in respect to its bearing stresses exceeding the limit of its elasticity. It must, therefore, be admitted, that the science of strength of materials, so all-important in engineering, is but little advanced; and the part

of it relating to the so-called hardness of different solids least of all; there being in it no step toward quantitative measurement or reckoning in terms of a definite unit.

A similar confession might have been made regarding electric science, as studied even in the chief physical laboratories of the world, ten years ago. True, Cavendish and Coulomb last century, and Ampère, and Poisson, and Green, and Gauss, and Weber, and Ohm, and Lentz, and Faraday, and Joule, this century, had given us the mathematical and experimental foundation, for a complete system of numerical reckoning in electricity and magnetism, in electro-chemistry, and in electric thermodynamics; and as early as 1858 a practical beginning of definite electric measurement had been made, in the testing of copper resistances, insulation resistances, and electro-static inductive capacities, of submarine cables. But fifteen years passed after this beginning was made, and resistance coils and ohms, and standard condensers and microfarads, had been for ten years familiar to the electricians of the submarine-cable factories and testing-stations, before anything that could be called electric measurement, had come to be regularly practised in most of the scientific laboratories of the world. I doubt whether, ten years ago a single scientific-instrument maker or seller, could have told his customers whether the specific conductivity of his galvanometer coils, was anything within 60 per cent. of that of pure copper; and I doubt whether the resistances of one in a hundred of the coils of electro-magnets, galvanometers, and other electro-magnetic apparatus, in the universities, and laboratories, and lecture establishments of the world, were known to the learned professors whose duty it was to explain their properties, and to teach their use to students and pupils. But we have changed all that; and now we know the resistances of our electro-magnetic coils, generally speaking, better than we know their lengths; and our least advanced students in physical laboratories, are quite able to measure resistances through a somewhat wide range with considerable accuracy. I should think, indeed, that with the appliances in ordinary use, they are more likely to measure resistances of from 100 to 10,000 ohms to an accuracy of $\frac{1}{10}$ per cent., than they are to be right to 1 millimetre in a metre in their measurements of length. It certainly is a very surprising result, that in such a recondite phenomenon—such a subtle quality to deal with—as electric resistance, which is so very difficult to define, and which we are going to learn is a velocity, every clerk in a telegraph station, the junior students and assistants in laboratories, and even workmen in electric lighting establishments, are

perfectly ready to measure, more accurately than you would measure the length of ten feet of wire, the resistance of electric conductors in definite absolute units.

I suppose, too, nearly every apparatus-room and physical laboratory possesses a micro-farad, but I am afraid its pedigree is not often known; and if its accuracy within 10 per cent. were challenged, I doubt whether, in many cases, any one, whether maker, or possessor, or other electrical expert, could be found to defend it. As for our electro-static apparatus, I confess that I do not know the capacity of a single one of the two or three dozen Leyden jars which, in 1846, I inherited in the Natural Philosophy apparatus-room of the University of Glasgow, or which I have made from time to time during the thirty-seven years passed since that date. I would fain hope that I am singular in such a confession, and that no other professor of Natural Philosophy in the world, would let a Leyden jar be put on his lecture-room table, without being able to tell his students its capacity in absolute measure. The reckoning of Leyden-jar capacity in square inches of coated glass—thickness and specific inductive capacity not stated—ought to be as much a thing of the past, as is the reckoning of resistances in terms of a mile of wire —weighing 14 grains to the foot, of ordinary commercial copper, specific resistance not stated (perhaps 45 per cent.? or 70 per cent.? or 98 per cent.? of the conductivity of pure copper). And as to practical measurement of electromotive force, we have scarcely emerged one year, from those middle ages when a volt and a Daniell's cell were considered practically identical,—to the higher aspiration of measurement within 1 per cent. It seems, indeed, as if the commercial requirements of the application of electricity to lighting, and other uses of every-day life, were destined to cause an advance of the practical science of electric measurement, not less important and valuable in the higher region of scientific investigation, than that which, from twenty to thirty years ago, was brought about by the practical requirements of submarine telegraphy.

There cannot be a greater mistake, than that of looking superciliously upon practical applications of science. The life and soul of science is its practical application, and just as the great advances in mathematics have been made through the desire of discovering the solution of problems which were of a highly practical kind in mathematical science; so in physical science many of the greatest advances that have been made, from the beginning of the world to the present time, have been made in the

earnest desire to turn the knowledge of the properties of matter to some purpose useful to mankind.

The first step toward numerical reckoning of properties of matter, more advanced than the mere reference to a set of numbered standards as in the mineralogist's scale of hardness, or to an arbitrary trade standard, as in the Birmingham wire-gauge, is the discovery of a continuously-varying action of some kind, and the means of observing it definitely, and measuring it in terms of some arbitrary unit or scale division. But more is necessary to complete the science of measurement in any department; and that is the fixing on something absolutely definite as the unit of reckoning, which, with reference to electric and magnetic science, is the subject of my lecture of this evening.

In electricity, the mathematical theory and the measurements of Cavendish, and in magnetism, the measurements of Coulomb, gave, one hundred years ago, the requisite foundation for a complete system of measurement: and fifty years ago the same thing was done for electro-magnetism by Ampère.

I speak of electricity, of magnetism, and of electro-magnetism. Now I must premise, as a matter of importance in respect of some of the technical details which we shall have to consider a little later, that magnetism must be held to include electro-magnetism. Electro-magnetism and magnetism are one and the same thing. Electro-magnetic and electro-static force, which are very distinct just now, are two things which deeper science may lead us to unite, in a manner that we can scarcely see at present. We have the foundation in the last century of Cavendish for electricity, and of Coulomb for magnetism, which falls in perfectly with what I shall have to say a little later on, in respect of Gauss and Weber's work, of magnetism and electro-magnetism. I say this, because there has been some little discussion in respect to the magnetic unit and the electro-magnetic unit, as if the magnetic unit might be something different from the electro-magnetic unit, or the electro-kinetic unit. It will simplify matters if we think merely of a magnetic force, whether it be due to a steel magnet, or to a wire conveying a current; and make no distinction so far as measurement is concerned, through the range of the science of magnetism, including electro-magnetism. We shall find that we have the two capital subjects; electricity and electro-static force one of them: magnetism and electricity in motion through conductors, and magnetic and electro-magnetic force, the other. The first complete method of scientific measurement for any of these subjects was that of Gauss, in his system of absolute measurement for

terrestrial magnetism so splendidly realised by Gauss and Weber in their Magnetic Society of Göttingen, which gave the starting impulse for the whole system of absolute measurement as we now have it, throughout the range of electric science. In fact, Weber himself, after realising absolute measure in terrestrial magnetism in conjunction with Gauss, carried it on through the field of electro-magnetism in his "Elektrodynamische Maasbestimmungen,"[1] and thence into electro-statics in his joint work with Kohlrausch, under the same title, "Elektrodynamische Maasbestimmungen."[2] The now celebrated "v" (velocity), which Maxwell in his electro-magnetic theory of light, pointed out to be not merely by chance approximately equal to the velocity of light, but to be probably connected physically, in virtue of the forces concerned, with the actual action or motion of matter which constitutes light, was found to be approximately 300,000 kilometres per second.[3]

As early as 1851 I commenced using the absolute system in the reckoning of electromotive forces of voltaic cells, and the electric resistances of conductors, in absolute electro-magnetic units;[4] and after advocating the general use of the absolute system, both for scientific investigation and for telegraph work, for ten years, I obtained in 1861 the appointment of a Committee[5] of the British Association on Electrical Standards.

This committee worked for nearly another ten years through the whole field of electro-magnetic and electro-static measurement, but chiefly on standards of electric resistance, until in its final report, presented to the Exeter meeting in August 1869, it fairly launched the absolute system for general use; with arrangements for the

[1] Leipsig, 1852. An earlier publication of one of the most important parts of the work was Weber's paper, "Messungen galvanischen Leitungswiderstände nach einen absoluten Maasse." Poggendorff's Annalen, March 1851.

[2] Poggendorff's Annalen, August 10, 1856.

[3] The exact number given by Weber and Kohlrausch is 310,740; but more recent investigations render it probable that this number may be 3 or 4 per cent. too great. See also Gray's "Absolute Measurements in Electricity and Magnetism." Macmillan & Co. London, 1883.

[4] See my papers "On the Mechanical Theory of Electrolysis," and "Applications of the Principle of Mechanical Effect to the Measurement of Electromotive Forces, and of Galvanic Resistances in Absolute Units," both published in the 'Philosophical Magazine,' December 1851; now constituting Articles LIII. and LIV. of my reprint of "Mathematical and Physical Papers," vol. i., 1882.

[5] The reports of this Committee were published at intervals from 1861 to 1869 in the British Association volumes of Reports for the respective years. These, along with other contributions to the subject, were collected and, under the editorship of Prof. Fleeming Jenkin, published by Spon, London and New York, 1871.

supply of standards for resistance coils in terms of a unit, first called the British Association unit, and afterwards the Ohm; of which the resistance reckoned in electro-magnetic measure was to be, as nearly as possible, 10,000 kilometres per second.

In regard to the name of "ohm," I may mention that a paper was communicated to the British Association in 1861 by Sir Charles Bright and Mr. Latimer Clark, in which the names that we now have, with some slight differences, were suggested; and a complete continuous system of measurement was proposed, which did not fulfil certainly all the conditions of the absolute system, but which fulfilled some of them in an exceedingly useful manner for practical purposes. To Sir Charles Bright and Mr. Latimer Clark, therefore, is due the whole system of names as we have it now, ohms, volts, farads, and micro-farads. From 1870 or 1871 forward, the absolute system, with the approach to accurate realisation of it given by the British Association unit, has been in general use in England and America; but another decade has passed, a rather long one, before the definitive practical adoption of the absolute system by France, Germany, and other European countries, as decreed by the International Conference, for the determination of Electric Units, held at Paris in October 1881. The decision adopted was, not to take the British Association unit. Doubt was thrown upon its accuracy, which we shall see was well founded. The question of a strict foundation for a metrical system was before the Conference, and it was inclined to adopt the absolute system, but the question occurred, "What is the ohm?" Who can see an ohm? Who can show what an ohm is? Who can measure the resistance of any conductor for us, in this absolute measure of Weber's? Weber's own measurement differed greatly from that of the British Association. Several experimenters, in endeavouring to verify or test the British Association measurement, arrived at results which were discordant among themselves, and therefore could not be confirmatory of the British Association measurement. Things were in this doubtful state, and the Conference had a very important practical question to decide. A proposal had been before the world for ten years at least, to found accurate measurement of electrical resistance upon a material obtainable in uniform quality and by easy precautions in a state of perfect purity, or sufficiently nearly perfect to fit it practically for the purpose in question, which is,—the giving of a standard for the measurement of resistance. The Siemens unit, founded upon the specific resistance of mercury, had been proposed. The great house of Siemens (Berlin and London), our

distinguished *confrère*, Sir William Siemens, and his distinguished brother, Dr. Werner Siemens, worked upon this subject in the most thorough and powerful way—the measurement of resistances in terms of the specific resistance of mercury—in such a manner as to give us a standard which shall be reproducible at any time and place, with no other instrument of measurement at hand than the metre measure. I say, the system of measurement of resistance on a mercury standard had been worked out, and its practicability demonstrated. Werner and William Siemens themselves were both present at the conference, and they joined heartily in the proposal to adopt an absolute system, but the question was how to make a beginning; and the answer adopted by the Conference, was to ask for a definition of an absolute system in terms of a column of mercury. The column of mercury was the one standard in existence, that could be reproduced otherwise than by merely copying from one wire to another; and it was naturally adopted as the foundation upon which a standard, if not a practical unit to be used, should be founded. In short, then, the finding of the Conference was to this effect: that as soon as good evidence is given of a sufficiently near measurement for practical purposes, of the resistance of any conductor—be it a piece of wire or a column of mercury—as soon as such measurement should be made, with evidence that it is accurate enough for practical purposes, then the unit which the British Association had aimed at should be adopted; but it was to be left to the judgment and the convenience of the users of standards when to make the change, should a change be necessary, from the British Association unit as the ohm, or from the Siemens unit, to bring measurement into more close agreement with the absolute reckoning. What had been done by Lord Rayleigh and Mrs. Sidgwick, had left very little room for doubt but that the British Association unit was in error to the extent of 1·3 per cent. The Siemens unit had the advantage of being somewhat approximately equal to the desired absolute unit, though not professing to be an absolute unit at all. It was simply the resistance of a column of mercury at zero temperature, a metre in length and a square millimetre in section. There were great difficulties in the reproduction of the Siemens unit, in the earlier times of the investigation; but Dr. Werner Siemens, and Lord Rayleigh, and Mrs. Sidgwick, and many other workers besides, all working to compare with the British Association unit, obtained results which finally left no doubt whatever as to the true relation. Dr. Werner Siemens' result found the mercury unit to be 0·9536 of the British Association unit; Lord

Rayleigh and Mrs. Sidgwick found it 0·9542, which is an exceedingly close agreement, being within $\frac{1}{10}$ per cent. of the result of Dr. Werner Siemens. A result differing by nearly 1 per cent. had been obtained by Matthiessen and Hockin a good many years before, when the precautions necessary to reproduce the mercury standard with absolute accuracy, were not so well known as, in the course of a few years after their work, they came to be known. The final conclusion of Lord Rayleigh's work was, that the Siemens mercury unit is 0·9413, of what the conference at Paris agreed to define as the ohm; and that is the resistance measured by 1,000,000,000 centimetres per second. I am afraid that conveys a strange idea, but it is perfectly true as to the absolutely definite meaning of resistance. I shall have occasion to refer to the subject later, when I hope to explain this mysterious velocity of 10^9 centimetres per second. In the course of the thirty years from the time when telegraphy began to demand definite measurement, a great deal of accurate measurement in terms of variously defined units of resistance had been made. Many sets of resistance coils had been produced by the Varley brothers, and other instrument makers, and many scientific investigators in laboratories had produced standards, and sets of resistance coils were made according to those standards; but within the last twelve years all have merged into, either the Siemens, or the British Association unit. The British Association unit, as I have said, was an attempt at absolute measurement, which succeeded in coming within 1·3 per cent. of the 10^9 aimed at. *Copies* of the British Association unit were *accurate to* $\frac{1}{10}$ *per cent.* The Siemens unit was founded on another idea, but it gave results no less definite and no less convenient for a great multitude of practical applications, than did the somewhat nearer approach to a convenient absolute unit realised by the British Association Committee.

Gauss' principle of absolute measurement for magnetism and electricity, is merely an extension of the astronomer's method of reckoning mass in terms of what we may call the universal-gravitation unit of matter; and of the reckoning of force adopted by astronomers, in common with all workers in mathematical dynamics, according to which the unit of force is that force, which, acting on unit of mass for unit of time, generates a velocity equal to unit of velocity. The universal-gravitation unit of mass is such a quantity of matter, that if two quantities, each equal to it, be placed at unit distance apart, the force between them is unity.

The universal-gravitation method I refer to for this reason. There is a terrestrial-gravitation reckoning of force, according to the weight of the unit of mass; and after all, when we terrestrial creatures take a mass in our hand and feel the weight of it, it is a kind of measurement that we cannot do away with. The kilogram, or the pound, or the ounce, is a thing we have to deal with; we have it in our hand, and we cannot help using it to give us y its *heaviness* a reckoning of force. A local gravitation unit of force, means the weight of a gram in London, in Glasgow, at the Equator, or anywhere else; and it is a convenient unit; but the common mode of measuring force by reference to weight without reference to locality is not definite, because the weight of a gramme is different here from what it is at the Equator. The heaviness of a pound or a gram is greater by a two-hundredth at either pole than at the Equator; or to give the exact figures, 0·00512. That is a difference of $\frac{1}{2}$ per cent., and if your accuracy is to be within a $\frac{1}{2}$ per cent., you cannot ignore the difference of the force of gravity in different places. But a vast number of measurements in engineering, and in the most ultra scientific work of scientific laboratories, does not aspire to so high a degree of accuracy; and for all such work the local or terrestrial-gravitation unit suffices, without specifying what the particular place is —only that it is somewhere or other on the face of the earth. For instance, moduluses of rigidity, moduluses of rupture, breaking strains of material, are stated accurately enough for engineering purposes, in terms of a ton weight per square centimetre, or pounds weight per square centimetre, or any other such mode of reckoning; or if I had not vowed never to mention inches, I would say tons per square inch, which is common (perhaps too common) in engineering. All such measurements ignore the difference of gravity in different localities, except some more precise measurements, in which an allowance for the force of gravity to reduce it to a standard of lat. 45° is made, or it is left to the person using the measurement to make the reduction. For all purposes, however, in which it would be desirable to apply a correction for the varying force of gravity in different places, it is convenient to use Gauss' absolute unit, and not the terrestrial-gravitation unit of force. I may say in passing, that the mere idea, which lurked or was visibly manifested, according to the degree of understanding, in the old formula of elementary dynamics $F = m\frac{dv}{dt}$, was an immense step; and the realisation of that idea, the bringing of it into practical use, has contributed more than

anything else I know, to the intelligent treatment of dynamic problems and their applications to both scientific and engineering matters. The system of absolute reckoning of force by Gauss cannot be too much commended, as a great and important practical improvement in the fundamental science of engineering and physics, the science of dynamics. It consists simply in defining the unit of force as that force which, acting on a unit of mass for a unit of time, generates a velocity equal to the unit of velocity. It leaves the units of mass, space, and time to be assumed arbitrarily; the gram, the centimetre, and the mean solar second, for example, as in the now generally adopted "C. G. S." system.

But the universal-gravitation system of the dynamical astronomer defines the unit of mass in terms of the unit of space and the unit of force. I need not repeat the definition. Thus we have the interlocking of two definitions:—the unit of force defined in terms of the units of mass, space, and time; the unit of mass defined in terms of the unit of force and the unit of space. It might seem as if we were proceeding in a vicious circle; but the circle is not vicious,—the two definitions are logically and clearly inter-dependent. We have, as it were, two unknown quantities and two equations; and the elimination of one of the unknown quantities from the two equations, gives us the other explicitly. The two are mixed up in a somewhat embarrassing way in the primitive definitions, but when we disentangle them, we arrive at the simple result, which I shall state presently, of independent definitions of the unit of mass and the unit of force, each in terms of units of space and time chosen arbitrarily.

Though the units of force and mass thus defined, are essentially implied in all the regular formulas of physical astronomy, from those most elementary ones, which appear in the treatment of the undisturbed elliptic motion, according to Newton's inferences from Kepler's laws, up to the most elaborate working out of the lunar, planetary, and cometary theories, and the precession and nutation of the earth's axis; it has not been usual for physical astronomers to found any systematic numerical reckoning upon them, nor even to choose arbitrarily and definitively any particular units of length and time, on which to found the units of force and mass. It is nevertheless interesting, not only in respect to the ultimate philosophy of metrical systems, but also as full of suggestions regarding the properties of matter, to work out in detail the idea of founding the measurements of mass and force on no other foundation than the measurement of space and time. In doing so, we immediately find that the square of an angular velocity, is

the proper measure of density or mass per unit-volume; and that the fourth power of a linear velocity, is the proper measure of a force. The first of these statements is readily understood by referring to Clerk Maxwell's suggestion, of taking the period of revolution of a satellite revolving in a circle close to the surface of a fixed globe of density equal to the maximum density of water, as a fundamental unit for the reckoning of time. Modify this by the independent adoption of a unit of time, and we have in it the foundation of a measurement of density, with the detail that the density of the globe is equal to $3/(4\pi)$ of the square of the satellite's angular velocity in radians[1] per second; that is, the square of the satellite's velocity, multiplied by 3 and divided by 4π, measures the density of the globe. It may be a hard idea to accept, but the harder it is the more is it worth thinking of, and the more instructive in regard to the properties of matter. There it is, explain it how you will, that the density of water, the density of brass, the mean density of the earth, is measured absolutely in terms of the square of an angular velocity. I do not know whether it is generally known, that to Fourier are due those dimensional equations that appear in the British Association's volume of reports, and in Clerk Maxwell's book, and in Everett's useful book 'Units and Physical Constants.' The dimension for the reckoning of density is the square of an angular velocity on the universal-gravitation absolute system, and is therefore T^{-2}. Equally puzzling and curious, is a velocity to the fourth power for the reckoning of force, which we have next to consider.

The universal-gravitation reckoning of force, which we shall see is by the fourth power of a linear velocity, may be explained as follows. Find the velocity with which a particle of matter must be projected to revolve in a circle round an equal particle fixed at such a distance from it, as to attract it with a force equal to the given force. The fourth power of this velocity is the number which measures the force. Sixteen times the force will give double the velocity; eighty-one times the force will give three times the velocity, and so on.

Now if I were to say that the weight of that piece of chalk, is the fourth power of twenty miles an hour, I should be considered fit, not for this place, but for a place where people who

[1] The radian is the unit in which angular velocity is expressed. It is an angle of $\left(\frac{180^\circ}{\pi}\right)$ about $57^\circ{\cdot}3$ (or more correctly $57^\circ{\cdot}2958$). Thus an arm, or radius vector turning through an angle of about $57^\circ{\cdot}3$ per second, is moving with unit angular velocity; or if the arm makes a complete circle in one second its angular velocity is 2π.

have lost their senses are taken care of. I suppose almost every one present would think it simple idiocy, if I were to say that the weight of that piece of chalk is the fourth power of seven or eight yards per hour; yet it would be perfectly good sense.

Think now of an infinitesimal satellite revolving round the Earth—you ask, what is an infinitesimal satellite? To be "infinitesimal" for our present purpose, it must be very small in comparison with the Earth, so as not to cause sensible motion by its reaction on the Earth. Well, a 500-lb. shot is an infinitesimal satellite; though it is not, perhaps, infinitesimal in some of its aspects. There must be no resistance of the air, of course. Now fire it off with such a velocity that it will have a very flat trajectory, neither more nor less flat than the Earth, and it will continue going round and round the Earth. Find the velocity at which you must fire off the shot to make it go round the Earth, and, if there is no resistance of the air, there is our infinitesimal satellite. These somewhat pedantic words are justified, because "infinitesimal satellite" is nine syllables to express three or four sentences; that is our justification.

The semi-period of an infinitesimal satellite revolving round the Earth, close to its surface,[1] is equal to the semi-period of an ideal simple pendulum of length equal to the Earth's radius, and having its weighted end infinitely near to its surface; and therefore, when reckoned in seconds, is approximately equal to the square root of the number of metres (6,370,000) in the Earth's radius: because the length of a seconds pendulum (or the pendulum whose semi-period is a second) is very approximately 1 metre. Thus we find 2,524 mean solar seconds for the semi-period of the satellite, and its angular velocity in radians per second is therefore $(\pi/2524 =) 0{\cdot}001244$: hence the Earth's mean density, reckoned on the universal-gravitation system, with the mean solar second for the unit of time, is $[(0{\cdot}001244)^2 \times 3/(4\pi) =] 3{\cdot}70 \times 10^{-7}$; and, if we take (from Bailey's repetition of Cavendish's experiment),[2] the Earth's mean density as 5·67 times the maximum density of water, we find $6{\cdot}53 \times 10^{-8}$ for the maximum density of water according to the universal-gravitation reckoning. To measure mass we must now introduce a unit of length, and if we take this as 1 centimetre, we find that, as the mass of a cubic centimetre

[1] Thomson and Tait's "Natural Philosophy," 2nd edition, vol. i., part i., § 223.

[2] Mr. Cornu has criticised Bailey's method of reducing his observations, in respect to allowance for viscous diminution of the oscillations of the torsion-rod. He has expressed the opinion that Bailey's result should, if calculated on thoroughly correct principles, have been in close agreement with his own, which was 5·55.

of water at maximum density is very approximately equal to what is called a gram, the universal-gravitation unit of matter is $[1/(6{\cdot}53 \times 10^{-8}) =]$ $15{\cdot}3 \times 10^6$ grams, or 15·3 French tons; hence the unit force on the universal-gravitation system is $15{\cdot}3 \times 10^6$ dynes; or 15·6 times the terrestrial weight of a kilogram.

15·3 French tons, then (a French ton is 1·4 per cent. less than the British ton), is the universal-gravitation unit of matter. The time may come when the universal-gravitation system will be the system of reckoning; when 15·3 tons will be the unit of matter, and when the decimal subdivision of 15·3 French tons may be our metrical system, and grams may be as much a thing of the past as grains are now.

There is something exceedingly interesting in seeing that we can practically found a metrical system on a unit of length and a unit of time. There is nothing new in it, since it has been known from the time of Newton, but it is still a subject full of fresh interest. The very thought of such a thing is full of many lessons in science that have scarcely yet been realised, especially as to the ultimate properties of matter. The gram it will be remembered, is founded on the properties of a certain body, namely, water; but here, without invoking any particular kind of matter, simply choosing a certain definite length marked on a measuring rod, and a unit of time (how obtained, we shall consider presently), we can take up a piece of matter, and tell, in any part of the universe, how to measure its mass in definite absolute units.

Think now of the two units on which this universal-gravitation metrical system depends; the unit of length and the unit of time. The unit of length is merely the length of a certain definite piece of brass, or other solid substance used for a measuring rod, or the length between two marks upon it; it may be an inch, or a foot, or a yard, or a metre, or a centimetre, the principle is the same. The metre, it is true, was made originally as nearly as possible equal to the ten-millionth of the length of a certain quadrant of the Earth, estimated as accurately as possible from the geodetic operations of Messrs. Méchain and Delambre in 1792, performed for the foundation of the metrical system. But this merely gave the original metre measure, and what is meant by the metre now is a length equal to it, or to some authentic copy of it, which has been made from it as accurately as possible; and the one-hundredth part of the metre thus defined, is the centimetre which we definitively adopt as the unit of length.

Thus our unit of length is independent of the Earth, and is

perfectly portable, so that the scientific traveller roaming over the universe carries his measuring-rod with him; and need think no more of the Earth, so far as his measurement of space is concerned. But how about the mean solar second, in terms of which he measures his time? What of it, if he has left the Earth for good; or if, even without leaving the Earth, he carries on his scientific work on the Earth through a few million years, in the course of which the period of the Earth's rotation round its axis, and its revolution round the sun, will both be very different from what they are now? If he takes a good watch or chronometer with him, well rated before he leaves the Earth, it will serve his purpose as long as it lasts. What it does is merely to count the vibrations of a certain mass under the influence of a certain spring (the balance-wheel under the influence of the hair-spring). If, for any secular experiment he has in hand, he wishes to keep up a continuous reckoning of time, he must keep his watch always going, and not a vibration will be lost in the counting performed by the hands. But if he merely wishes to keep his unit of time, and to make quite sure that, any number of million years hence, this shall be within one-tenth per cent. of its present value, he should take a vibrator better arranged for permanence and for absolute accuracy, than the balance-wheel with its hair-spring of a watch or a chronometer. A steel tuning-fork, which has had its period of vibration determined for him, before he leaves the Earth, by Professor Macleod or by Lord Rayleigh, will serve his purpose. By measuring the period in terms of mean solar seconds, with the prongs up, and horizontal, and vertically down, he will be able to eliminate the slight effect of terrestrial gravity; and he will have with him a time-standard that will give him the mean solar second, as accurately as his measuring-rod gives him the centimetre, in whatever part of the universe, and at whatever time, now or millions of years later, he has occasion to use his instruments.

I hope that you will not feel that I am abusing your good nature with an elaborate frivolity, when I ask you to think a little more of the unital equipment of our ideal traveller, on a scientific tour through the universe. For myself, what seems the shortest and surest way to reach the philosophy of measurement,—an understanding of what we mean by measurement, and which is essential to the intelligent practice of the mere art of measuring,—is to cut off all connection with the Earth, and think what we must then do, to make measurements which shall be definitely comparable with those which we now actually make, in

our terrestrial workshops and laboratories. Suppose, then, the traveller to have lost his watch and his tuning-fork and his measuring-rod; but to have kept his scientific books, or at all events to have in his mind, a full recollection and understanding of their contents: how is he to recover his centimetre, and his mean solar second?

Let us consider the recovery of the centimetre first. Wherever he is let him make a piece of glass, like this which I hold in my hand, out of materials which he is sure to find, in whatever habitable region of the universe he may chance to be; and let him with a diamond, or with a piece of hard steel, or with a piece of flint, engrave on it one thousand equidistant parallel lines, upon a space which may be about the breadth of his thumb, and which he may take as a temporary or provisional unit of length. He may help himself to engrave the glass by means of a screw cut in brass or steel, which he will easily make, though he has no tools, not even flint implements, to begin with. With a little time and perseverance he will make the requisite tools. Let him also make a temporary measuring-rod, and mark off equal divisions upon it, which may be of any convenient length, and need not have any relation to the definite provisional unit. Let him now make two candles, and light them and place them as you now see those on the table, at any convenient distance apart, measured on his measuring-rod. He holds the piece of ruled glass in his hand, close to his eye, as I hold this, and sees two rows of coloured spectrums, each with one of the candles in its centre. He turns the glass round till the two rows of spectrums are in the same line, and adjusts the parallelism of its plane, so as to make the distance from spectrum to spectrum a minimum. He moves backwards and forwards, as I do now, keeping his eye at equal distances from the two candles, until he sees each candle shooting up out of the yellow middle of a spectrum of the other candle, with no spectrum between the two candles. With this condition fulfilled, he measures the distance from the grating to the candles. Then, by the theory of diffraction, he has the proportion:—as the distance from the grating to the candles, is to the distance between the candles, so is the distance from centre to centre of the divisions on the glass, to the wave length of yellow light. This, he remembers, is $5{\cdot}892 \times 10^{-5}$ of a centimetre, and thus he finds the value in centimetres of his provisional unit.

[How easily this determination might be effected, supposing the grating once made, was illustrated by a rapid experiment per-

formed in the course of the lecture; without other apparatus than a little piece of glass with two hundred and fifty fine parallel lines engraved on it, two candles, and a measuring tape of unknown divisions of length (used only to measure the ratio between two distances). The result showed the distance from centre to centre of consecutive bars of the grating, to be 32 times the wave-length of yellow light. The breadth of the span on which the two hundred and fifty lines of the grating were ruled, was thus measured as ($250 \times 32 \times 5{\cdot}892 \times 10^{-5}$=) 0·47136 centimetre. According to the instrument maker this space was said to be 0·5 of a centimetre.]

Thus you see, by this hurried experiment with this rough-and-ready apparatus, we have been able to measure a length to within a small percentage of accuracy. A few minutes longer spent upon the experiment, and using sodium flames behind fine slits instead of open candles blowing about in the air, with more careful measurement of the ratio of the distances, might easily have given a result within one-half per cent. of accuracy. Thus the cosmic traveller can easily recover his centimetre and his metre measure.

But how is our scientific traveller to recover his mean solar second, supposing he has lost his tuning-fork? He may think of the velocity of light, and go through Foucault's experiment. That is a thing that can be done from the beginning, with nothing but cutting tools and pieces of metal to begin with. Let him get a piece of brass and make a wheel, and cut it to two thousand teeth. I do not know how many teeth Foucault used, but our traveller can go through the whole process, and set the wheel revolving at some uniform rate (not a known rate, because he has no reckoning of time); and he will tell what the velocity of the wheel is in terms of the velocity of light, which is known to be about 300,000 kilometres per second. If he is electrically minded, as this evening we are bound to suppose our scientific traveller to be, he will think of "v," or of an ohm. He may make a Siemens unit; that he can do, because he has his centimetre, and he finds mercury and glass everywhere. Then he goes through all that Lord Rayleigh and Mrs. Sidgwick have done. He will, with a temporary chronometer or vibrator, obtain a provisional reckoning of time, and he will go through the whole process of measuring the resistance of a Siemens unit in absolute measure, according to his provisional unit of time. His measurement gives him a velocity in, let us say, kilometres per this provisional unit of time, as the value of the Siemens unit in absolute measure. Then he knows from Lord Rayleigh and Mrs. Sidgwick, that the Siemens

unit in absolute measure is 9,413 kilometres per mean solar second; and thus he finds the precise ratio of his provisional unit of time to the mean solar second.

Still, even though this method might be chosen as the readiest and most accurate, according to present knowledge of the fundamental data, for recovering the mean solar second, the method by "v" is too interesting and too instructive, in respect to elimination of the properties of matter from our ultimate metrical foundations, to be unconsidered. One very simple way of experimentally determining "v," is derivable from an important suggestion of Clark and Bright's Paper, referred to above. Take a Leyden jar, or other condenser of moderate capacity (for example, in electrostatic measure, about 1,000 centimetres), which must be accurately measured. Arrange a mechanism to charge it to an accurately measured potential of moderate amount (for example, in electrostatic measure, about 10 c.g.s., which is about 3,000 volts), and discharge it through a galvanometer coil at frequent regular intervals (for example, ten times per any convenient unit of time). This will give an intermittent current of known average strength (in the example, 10^5 electrostatic c.g.s., or about 1/300,000 c.g.s. electro-magnetic, or 1/30,000 of an ampère), which is to be measured in electro-magnetic measure by an ordinary galvanometer. The number found by dividing the electrostatic reckoning of the current, by the experimentally found electro-magnetic reckoning of the same, is "v," in centimetres per the arbitrary unit of time, which the experimenter in search of the mean solar second has used in his electrostatic and electro-magnetic details. The unit of mass which he has chosen, also arbitrarily, disappears from the resulting ratio.

But there is another exceedingly interesting way—a way which, although I do not say it is the most practical, has very great interest attached to it, as being a way of doing the thing in one process—that is, by the method of electrical oscillations.[1] I should certainly like to see how a person who has lost his standards, after having recovered his centimetre (which he certainly would do by the wave-length of light), would succeed in recovering his unit of time by the following method. Take a condenser—a very large Leyden jar; electrify it, and connect the two poles through a con-

[1] See my Papers "On Transient Electric Currents," Glasgow Philosophical Society Proceedings, vol. iii., Jan. 1853, and Philosophical Magazine, June, 1853; now constituting Article lxii. of my reprint of "Mathematical and Physical Papers," vol. i., 1882.

ductor, arranged to have as large an electro-magnetic *quasi* inertia,[1] electro-magnetic self-induction—as possible. The method is given in Clerk Maxwell's "Electricity and Magnetism" (vol. ii. chap. xix.): it is too long to explain the details. Read the mathematical parts of Clerk Maxwell, read the British Association volume of Reports on Electrical Standards, and read Everett's "Units and Physical Constants"; get these off by heart from the first word to the last, and you will learn with far less labour than by listening to me. Take a resistance-coil of proper form for maximum electro-magnetic inertia,[2] and discharge the condenser through it; or rather start the condenser to discharge through such a coil, and you will have a set of oscillations, following exactly the same law as the oscillations of the water-level in two cisterns, which, having initially had the free water-level in one higher than in the other, are suddenly connected by a U-tube. Imagine two cisterns of water, connected by a U-tube with a stop-cock, and having the water higher in one cistern than in the other: now suddenly open the stop-cock, and the water-level will begin to fall in one cistern, and rise in the other. The inertia of the water, thus made to flow through the connecting U-tube, will cause it to flow on after it has come to its mean level in the two cisterns, and rise to a higher level in the one in which it was previously higher, and sink to a correspondingly low level in the other. Thus the water-level in each cistern would alternately be above and below the mean free level: the range of motion being gradually diminished, in virtue of the viscosity of the water, until after a dozen or two of oscillations, the amplitude of each becomes so small that you cannot notice it. Precisely the same thing happens in the case of the discharge of a condenser through a resistance coil of large electro-magnetic inertia: the resistance of the copper wire being like the viscous influence which causes the oscillations of water to subside. If, in his investigations throughout the universe, our traveller could meet with a metal which is about a million times as conductive as copper, he would make this experiment with much greater ease; but it is practicable with copper. It is certain from the observa-

[1] See on this subject my Paper "On the Mechanical Value of Distributions of Electricity, Magnetism, and Galvanism," read before the Glasgow Philosophical Society, January 1853, and published in their Proceedings (vol. iii.) for that date; also article "Dynamical Relations of Magnetism," Nichol's "Cyclopædia of the Physical Sciences," 2nd edition, 1860. These two Papers, with additions of date July 1882, now constitute Article lxi. of my reprint of "Mathematical and Physical Papers," vol. i., 1882.

[2] See Clerk Maxwell's Electricity and Magnetism, sect. 706.

tions made by Feddersen, Schiller, and others, that a great number of oscillations can be observed, and that the period, or semi-period of oscillation, can be determined with considerable accuracy.

If our scientific traveller wishes, by this beautiful experiment, once for all to determine his time reckoning, let him proceed thus. Let him take a coil, of which he knows the dimensions perfectly, having already gone through the preliminary process of measuring its electrical dimensions; or if he cannot measure these with sufficient accuracy (and there is enormous difficulty in finding the electric dimensional qualities of a coil by measurement), let him do it partly by direct measurement of its length and of linear dimensions of the figure into which it is wound, and partly by comparing it electro-magnetically with other coils. By an elaborate investigation he can find the electro-magnetic inertia of the coil in terms of his centimetre. And here, again, there is a curious kind of puzzle and apparent incongruity, when I say that the electro-magnetic inertia equivalent of a coil, is a length, and is measured as a numeric of centimetres. Let him make a condenser, and by building it up from small to large, let him learn the capacity of it in electrostatic measure. Let him begin with two plates or cylinders, or a sphere enclosed within a concentric sphere, and go on multiplying till he gets a capacious enough condenser of which he knows, in electrostatic measure, the electrostatic capacity. This, again, is a line. Now let him take the rectangle of those two lines, and construct the equivalent square—let him, geometrically or arithmetically, take the square root of the product of the two lines—and let him observe the period of electric oscillation that I have spoken of. Let him imagine the hand of a watch, going once round in the observed period. He has good magnetic eyes, and he sees the electro-magnetic oscillation, or he has appliances by which he can test it: the thing has been done. He sets in motion a little piece of wheel-work, with a hand going once round in the period of the oscillation. Now for a moment, let him imagine that hand to be equal in length to the square root of the product of those two lines—several million centimetres, or several thousand kilometres, if the coil and condenser are of dimensions convenient for the actual experiment, as we terrestrials might do it. The velocity of the end of that hand is "v." There he has this wonderful quantity "v." He has a hand going round in a certain time, and he knows that if that hand be of the calculated length, the velocity of the end of it is "v." This is interesting and instructive, and though I do not for certain know that it is very practicable it is

still, I believe, sufficiently so to be worth thinking of. I think it will be one of the ways of determining this marvellous quantity "v."

It is to be hoped that before long "v" will be known, in centimetres per mean solar second, within 1/10 per cent. At present it is only known that it does not *probably* differ 3 per cent. from $2{\cdot}9 \times 10^{10}$ centimetres per mean solar second. When it is known with satisfactory accuracy, an experimenter provided with a centimetre measure may, anywhere in the universe, rate his experimental chronometer to mean solar seconds, by the mere electrostatic and electro-magnetic operations described above, without any reference to the sun or other natural chronometer.

I have tried your patience, I fear, too long, but I have now only reached the threshold of my subject. We now must commence the consideration of electrical units of measurement. I need not go round defining quantities electrostatically and electromagnetically; you will find it all in Everett, and in the British Association volume of collected Reports by the first Committee on Electric Measurement. It is not for me to tell you of an ohm, a volt, a micro-farad, and so on; but there are two or three points that I should like to notice, and one is, the limitation of the so-called practical system. The absolute system goes from beginning to end in a perfectly consistent manner, with the initial conditions carried out all through; one of which, in the electromagnetic system, is that the electromotive force produced by the motion at unit speed, across the lines of force of a field of unit intensity, of a unit length of conductor, is unity. That you must carry out if the system is to be complete and consistent, and the dimensions of all your instruments and apparatus must all be all reckoned uniformly in terms of the unit of length adopted in the absolute definition. The ohm is 1,000,000,000 centimetres, or 10,000 kilometres, per second. If we are to make the ohm an absolute electro-magnetic unit with the second as the unit of time, we must take the earth's quadrant as the unit of length. If we take that consistently throughout, we need never leave this particular system and we need have nothing to do with C. G. S. We should have the Q. G. S. system pure and simple! But it would be obviously inconvenient to measure the dimensions of instruments, the diameters of wheels, and the gauges of wire in submultiples of the earth's quadrant. Imagine the horror of a practical workman, on hearing a scientific person say to him, "Give me a wire 1/1,000,000 of an earth-quadrant long, and 1/10,000,000,000 in diameter." Now wherein does the so-called practical system differ from the absolute system, and why is it

not to be as logical and complete as the absolute system? We would never leave the absolute system, if it gave us in all cases convenient numbers; and it does give us convenient numbers for the measurement of a current, its unit being ten times the "ampere" of the practical system. The unit of resistance in C. G. S., however, is too small, so is the unit of electromotive force. To get convenient numbers, we give names to certain multiples of units, that is all; and we use these multiples just as long as it is convenient, and not any longer. That is my idea of the practical system—to use it for convenience and as long as it is convenient; the moment it ceases to be convenient, to throw it overboard and take C. G. S. pure and simple. The Conference at Paris decided upon the practical system, by adopting the units which are now so familiar, the ohm, the volt (taken from the British Association recommendation), and the ampere. The coulomb was also added, and it was most satisfactory to get old Coulomb's name in—one of the fathers of electrical science. Then the watt was added by Sir W. Siemens, and it has been generally accepted, and has proved exceedingly convenient. But when you go farther with the practical system, and take anything that involves a magnetic pole or a magnetic field, you get lost in the trouble of adopting the earth's quadrant as unit of length, and the deviation from C. G. S. ceases to be convenient. Return then to C. G. S. pure and simple.

I spoke of the resistance of an ohm being measured in terms of a velocity. I should like to explain this in a few words. Imagine a mouse-mill set with its axis vertical. Put a pair of brushes at the tops and bottoms of the bars; put the brushes in the magnetic north and south plane through the axis, and set the mouse-mill to spin at any rate you please. Take a galvanometer like a tangent galvanometer, but with only an arc equal to the radius—an arc subtending an angle equal to about 57·3°—having its ends on the same level, whether above or below the level of the needles, and electrodes perpendicular to the plane of the arc connected with the brushes. The mouse-mill must be placed so far from the galvanometer, as not sensibly to influence it by direct electro-magnetic force. Now take the galvanometer, and turn the mouse-mill; let the length of each bar of the mouse-mill be a centimetre; but that would be a flea-mill rather than a mouse-mill—say, let each bar be 100 centimetres; turn the mouse-mill round fast enough to cause your galvanometer to be deflected 45°. Then one hundred times the velocity of the bars is equal to the resistance in the circuit. Double resistance

requires double velocity; half resistance requires half velocity to give the prescribed 45° deflection. There, then, is the rationale of 10,000 kilometres per second, or 1,000,000,000 centimetres per second being the measure of resistance. While we thus measure resistance in electro-magnetic measure by a velocity, we measure a conductivity in electrostatics by a velocity. I have given a very simple explanation of this also in a statement quoted by Sir William Siemens in his presidential address to the British Association at Southampton in 1882. The velocity at which the surface of a globe must shrink towards the centre, to keep its potential constant, when it is connected to the earth by a wet thread, measures the conducting power of that wet thread. Double conducting power will require double velocity of shrinkage, that is, the globe must shrink twice as fast not to lose its potential. With a very long semi-dry thread the globe may shrink slowly. Suppose we have a globe insulated in the air of this room for electrical experiment, and connected with the ground by a silk thread. If you have an electrometer to show the potential, you will see it gradually sink. You might imagine that dust in the air would carry off electricity, but in truth practically the sole loss is by this semi-dry silk thread. When you see the potential sinking, imagine you see the globe shrinking slowly, so as to keep its potential constant, while it is gradually losing its electric charge little by little: the velocity with which the surface must shrink towards the centre to keep the potential constant, measures the conducting power of the thread in electrostatic measure. Thus we learn how it is a velocity which measures in electrostatic measure the conducting power of a certain thread or wire. But, as we have seen in electro-magnetic measure, the resistance of the same thread or wire is measured by another velocity. The mysterious quantity "v" is the square root of the product of the two velocities. Or it is the one velocity which measures in electro-magnetic measure the resistance, and in electrostatic measure the conductivity, of one and the same conductor: which must be of about 29 ohms resistance, because experiment has proved "v" to be not very different from 290,000 kilometres per second.

I have spoken to you of how much we owe to Sir Charles Bright and Mr. Latimer-Clark for the suggestion of names. How much we owe for the possession of names, is best illustrated by how much we lose—how great a disadvantage we are put to—in cases in which we have not names. We want a name for the reciprocal of resistance. We have the name "conductivity," but we want a

name for the unit of conductivity. I made a box of resistance coils thirty years ago, and another fifteen years ago, for the measurement of conductivity, and they both languished for the want of a name. My own pupils will go on using the resistance box in ohms, rather than the conductivity box, because, in using the latter, it is so puzzling to say, "The resistance is the reciprocal of the sum of the reciprocals of these resistances." It is the conductivity that you want to measure, but the idea is too puzzling; and yet for some cases the conductivity system is immensely superior in accuracy and convenience to that by adding resistances in series. For the reciprocal of an ohm in the measurement of resisting power—for the unit reckoning of conductivity which will agree with the ohm—it is suggested to take a phonograph and turn it backwards, and see what it will make of the word "ohm." I admire the suggestion, and I wish some one would take the responsibility of adopting it; we should then have *mho* boxes of coils at once in general use. With respect to electric light, what is it we want to measure by the current galvanometer? We have a potential galvanometer, and we have a current galvanometer. Everybody knows what we want to measure with the potential galvanometer. The servant in every house that is lighted electrically knows about potentials; and if in reading the galvanometer he sees it is down to 80 volts he knows that something is wrong, and will at once go to the engine-room and cause 84 volts to be supplied; supposing, for example (as in the case of my own house, temporarily, until I can get two-hundred-volt lamps), that the proper potential is 84 volts. But in the current galvanometer there are so many divisions indicating, it may be, the number of amperes in the current. But after all, what do we want besides a knowledge of the potential? It is the sum of the reciprocals of the resistances in the circuit. In the multiple-arc system each fresh lamp lighted adds a conductivity. In a circuit of Edison or Swan hundred-volt lamps, in each of which you have a current of 0·7 of an ampere, and therefore a resistance of 143 ohms, how convenient it would be, in putting on a lamp,—adding a certain conductivity,—if we could say we add a *mho*, or a fraction of a *mho*, as the case may be. I do not say that *mho* is the word to be used, but I wish it could be accepted, so that we might have it at once in general use. We shall have a word for it when we have the thing, or rather I should say, we shall have the thing when we have the word. The Appendix to the 1862 Report of the first British Association Committee on Electric Measurements contains a description of a "Resistance Measurer"

invented by Sir William Siemens, and a "Modification of Siemens Resistance Measurer," by Professor Jenkin. This instrument gives directly the resistance of a conductor, by means of an instrumental adjustment, bringing a magnetic needle to a zero position for each observation. In the original Siemens instrument the adjustment is a shifting of two coils by translational motion, and the conductivity is read on a scale of equal divisions adapted, by means of a curve determined by experiment, to give a reading of the required resistance. In Jenkin's modification the mechanical arrangement is much simplified by the adoption of a different electro-magnetic combination; and the required resistance is given by the tangent of the angle through which the coils must be turned to bring the needle to zero. A similar instrument to give conductivity by a simple reading, without any adjusting or "setting" for each observation, is easily made. I made such an instrument in 1858, being simply a galvanometer with controlling resistance coils instead of controlling magnets.[1] Such an instrument at once gives conductivity, and you want a name (suppose you adopt *mho*) for the unit of conductivity, and call the instrument a mhometer. The rule, for resistances in series, would be, the sum of the reciprocals of mhos, is equal to the number of ohms; and, for conductivities in parallels, the sum of the reciprocals of ohms, is equal to the number of mhos. The number of mhos, or of millimhos, will then measure the number of lamps in the circuit. The domestic incandescent lamp of the early future ought to be, and we hope will be, a one-millimho lamp, to give a 10- or 12-candle light with the Board of Trade regulated 200 volts of potential. Thus the lamp-galvanometer, or lamp-meter, may have its scale divided to one millimho to the division, and the number read on its scale at any time will be simply the number of lamps lighted at the time. The instrument will also have the great advantage of being steady, notwithstanding the variations of the engine. A potential instrument on an electric-light circuit at best is always somewhat variable, because the potential varies a good deal—within 1 or 2 per cent. perhaps—but the resistance in the lamps varies exceedingly little. The mho-meter will in these circumstances be an absolutely steady instrument; you will not see it quiver, even though the engine is irregular. The potential galvanometer will show you how much unsteadiness there is, to be complained of or to be corrected.

[1] This instrument is represented in Fig. 6 of my 1858 patent for "Improvements in Testing and Working Electric Telegraphs."

Lastly, as to the objects to be aimed at in respect to the use of this great system of units. Nothing can be much more satisfactory than is the measurement of somewhat large resistances, as we have it habitually at present; but if we want a little more method for low resistances, it will be helped very much by the use of the mho boxes of conductivities which I have indicated. The great thing we want now in the way of practical electric measurement, is a good standard of electromotive force. That was the chief object of a recent British Association Committee, but it has not yet been satisfactorily attained for practical purposes. Standard cells serve for the purpose to some extent, but we want something better, something of the nature of an electro-dynamometer, to give a good steady idiostatic potential gauge, by which the constant of any electrometer or ordinary galvanometer may be easily and accurately tested. That is an object to be sought; there are plenty of ways of attaining it, and I hope, before another year has passed, to see it realised in many ways, certainly in one way.

As to the science of electricity, the great want in the way of measurement just now is the accurate measurement of ("v") the ratio between the electrostatic and the electro-magnetic units; and I hope that scientific investigators will take the matter up, and give to it an accuracy like that which Lord Rayleigh has given to the measurement of the ohm.

A most interesting point remains. It is Joule's work, reported on by the British Association Committee:—see volume of Reports on Electrical Standards, p. 138. It was only in my preparation for this lecture that I came upon it, and put the figures definitively together. Joule, with a modesty characteristic of the man, and with a magical accuracy chracteristic of his work, made, at the request of the British Association, an investigation of the heating effect of a measured current in a definite way, according to the measure of resistance of the British Association ohm, supposed then to be 10^9 C. G. S. units of resistance; and he himself considered that the electrical measurement which he then made, was more accurate than his old frictional measurement of the mechanical equivalent of the thermal unit could be. The result obtained, assuming the British Association ohm to be absolutely correct, gave the mechanical equivalent as 782·2 foot-pounds, instead of 772 which he had made it before, and he expressed himself willing to make a new determination of it by the frictional method. But now let us put ourselves in the position of 1866, the date of this report, with these competing determinations of the ohm: that obtained by the British Association method of spinning

coils; and by Joule's electro-thermal method with the dynamical value of the thermal unit, as was given by his frictional method. Supposing that his electro-thermal method was right, then what we are to infer is not that the result is the mechanical equivalent, but that the British Association unit was not 10^9, as it was supposed to be, but $10^9 \times 0{\cdot}98699$. Thus this experiment was virtually Joule's determination of the resistance of the British Association ohm in absolute measure. Lord Rayleigh's determination is $10^9 \times 0{\cdot}98677$, a difference of 2 in the 4th place, within about 1/50 per cent. There is perfect magic in the accuracy of Joule's work; it is not a matter of chance. I think, between Joule, Lord Rayleigh, Mrs. Sidgwick, and others, we cannot have much doubt now, what is the absolute value of the Siemens unit, or of the British Association unit. I advise everybody to take the Rayleigh ohm unit, instead of the British Association ohm. I have begun to do so, and I mark everything R. O. You may have everything in the British Association unit, but reduce, if you please, to Rayleigh ohms by the reducing factor 0·98677. Volts must be reduced in the same ratio. The old estimate which I made in 1851 from Joule's experiment, for the absolute electromotive force of a standard Daniell cell, was 1·07 volts; and after thinking it was 1·078 for ten years, because of the British Association unit, we come back to correct it, and find it is 1·07. So much for the volt. But we want far more accurate instruments and methods connected with other parts of electric measurement, especially electromotive force and capacity, electro-static, or electro-magnetic, with the comparing number "*v*." These are the things we want to advance and perfect, to give a satisfactorily scientific character, to this great system of absolute measurement, of which I have endeavoured to trace and explain the origin.

A vote of thanks having been passed by acclamation to Sir William Thomson for his lecture,

Sir WILLIAM THOMSON said: I thank you very much for your kindness in awarding me this vote of thanks, and for the patience with which you have listened to me. I feel deeply the imperfection of what I have put before you. I wish I could have made it more clear, and placed it before you more methodically. All I can say is, that I have done my best, and I am much obliged to you for your patience.

Mr. HAWKSLEY: Mr. President, a very important duty has devolved upon me,—a duty which I have the greatest pleasure

in discharging, and in which I am sure you will assist me by your generous acclamations. This is the last of the lectures of this year. We have had these lectures delivered by most eminent men on subjects which, to most of us, had been previously not altogether known. The lectures have been of great importance and have communicated to us a large amount of knowledge, and they have made upon our minds permanent impressions by the very elegant experiments by which they have been for the most part demonstrated. It is therefore my duty to propose a vote of thanks to our friend, Mr. Preece, for his very excellent lecture on the progress of Telegraphy; also to Sir Frederick Bramwell for his illustrations on Telephones; then to Sir William Siemens for the illustrations he gave us with regard to the Transmission of Electrical Energy; also to our friend Dr. Hopkinson for the very scientific lecture he gave us on Electric Lighting—I do not altogether agree with him for certain reasons, but I must express my indebtedness to him, because I received information from him which I did not previously possess;—then, again, to our friend Sir Frederick Abel, to whom we were very much indebted for many explanations on the power of explosives, and for the very safe and pleasing way in which at the conclusion of the lecture he succeeded in blowing us all up; lastly (although it now comes a second time), to Sir William Thomson for the most amusing, and at the same time scientific lecture (which I mean to read in order that I may understand it the better) which he has been pleased to deliver this evening.

The vote of thanks having been carried,

Sir FREDERICK ABEL said: As an Honorary Member of the Institution, it is my privilege, on behalf of the eminent colleagues with whom I have been associated in this course, to return our hearty thanks for the manner in which you have received our efforts to make these evenings instructive to you, and to endeavour to deal with subjects of special practical, as well as scientific, interest. We feel that in thanking you heartily for the cordial manner in which you have received these efforts, we must accord a large portion of the acknowledgments you have awarded us to two gentlemen—in the first place to Mr. Forrest for the admirable manner in which he has organised these lectures; he has been our General who has led us triumphantly through this little campaign, and I trust he will be the General of many similar successful campaigns; and, secondly, we owe great thanks to Sir William Thomson's ideal Robinson Crusoe.

Mr. CARLETON BAYNES: I am sure we must not separate without

expressing our hearty thanks to the Council and Secretary for the excellent lectures to which we have had the privilege of listening. For thirty-three years I have been connected with this Institution, and I have noticed very many expansions and adaptations of machinery to suit the wants of the profession, but there is none that has shown the excessive care and attention to the wants that arise, more than these lectures. The getting of these eminent men each to lecture on his specialty is a masterly step, for which I think we must record not only our great thanks, but our admiration, to the Council and our Secretary.

The vote of thanks was carried by acclamation.

Sir JOHN COODE: Every good soldier is bound to obey his general officer, and I therefore obey the command that has reached me from headquarters. I find that I am expected to return thanks on behalf of the Council, and I do so with very great pleasure. I can assure you that to every member of the Council the success of these lectures has been a source of unmitigated gratification. With whom the idea originated I cannot say, but this I can answer for, that when it was propounded at the council table it was received with the greatest cordiality. The Council determined, so far as they were able, to do everything to bring the lectures to a successful issue, and that, I am happy to find, has been done. On behalf of the Council, I tender to you our most sincere thanks for your kindness.

INDEX.

A B C telegraph, 11
Abbot, General, his investigations on submarine mines, 143
Abel, F. A. "Electricity applied to Explosive Purposes," 107. Remarks as to ditto, 148—Vote of thanks to, 148
Abel fuze, the, 113 *et seq.*
Accidents to submarine telegraph-cables, 9
Alliance Company's magneto-electric machine, 60
Alternate-current machines, 66
America, extended use of telephones in, 52
American Civil War, use of torpedoes and electrically-fired submarine mines in the, 137
Ampère (Unit), 77. Ditto, A.M., discovery of reciprocal mechanical force exercised by electric currents, 87
Antwerp, siege of, use of torpedoes by the Duke of Parma at the, 139
Armstrong, Sir W., his opinion of the thermo-battery, 57; his utilization of a waterfall to produce electrical energy, 72; hydro-electric exploder of, 122
Atmospheric electricity, accidental discharge of mines by, 130
Automatic system, Wheatstone's, 16
Ayrton, W. E., and Perry, J., instruments devised by, for measuring electricity, 78

Barlow, W. H., his invention of the logograph, 28
Batteries, chemico-electrical, used in telegraphy, 3
Baudot's system of multiple telegraphy, 18
Baynes, C., proposer of vote of thanks to Council and officers, 175
Bazalgette, Sir J. W., 148
Beardslee's electrical exploder, 121
Bell, A. G., his invention of the telephone, 30; of the photophone, 45
Berlin Exhibition of 1879, electric railway at the, 73
Bickford's instantaneous fuze, 145
Bichromate of potash battery, the, 3
Bidder, G. P., 1
Bidwell, Shelford, illustrator of Mr. Barlow's logograph, 30
Blake transmitter, 47
Blasting, electrical, 107 *et seq.*
Bramwell, Sir F. "Telephones," 26—Vote of thanks to, 55
Breguet's electrical exploder, 121
British Association, Committee of 1861 on electrical standards, 153
Brown, E. O., 119, 148
Browning's electrical exploder, 121
Brunel, I. K., 1
Brunlees, J., 22, 55, 80, 106
Brunton. *See* Statham.
Burgoyne, Sir J. F., his opinion as to firing by electricity, 109 *et seq.*
"Burster," or fuze, employed in early electric firing, 110

C. G. S. system, the, 158
Cable-companies, electric, statistics of, 21; list of, 25
Carbon transmitter, Edison's, 40
Cavendish's mathematical theory and measurements of electricity, 152
Centimetre, mode of obtaining the, 164

"Challenger," H.M.S., beneficial results of the observations of, to submarine telegraphy, 8
Characteristic curves, 95
Circuit-closer, Matheson's, 142; Striedinger's, 147.
Clerk Maxwell's machine to illustrate the laws of induction, 84
Commercial uses of the telephone, 51
Conductors, electrical, materials forming, 4
Coode, Sir J., reply to vote of thanks, 176
Cooke, Sir W. F., original double-needle, instrument of, 10
Cost of electric lighting in London, 105.
Cottrell, —, his illustration of sand-figures produced by the vibration of a metallic plate, 34
Coulomb, C. A., measurement in magnetism, 77, 152
Crimean War, use of electrical firing in the, by the Russians, 118, 136

Daniell battery, 3; first use of the, in connection with firing by electricity, 109
Delambre. *See* Méchain.
De Meritens magneto-electric machine, the, 65
Deprez, Marcel, his experiments on the transmission of power by electricity, 72.
Disk, metallic, the, important functions of, in producing telephonic vibrations, 33.
Diving, assistance to, rendered by the telephone, 52
Dolbear's telephone, 47
Double-needle instrument, 10
Du Moncel, T., his mode of firing electrical blasts, 118
Duplex telegraphy, 14
Dynamo-electric machine, the, 60; experiment with, 66; definition of the, 87

Ebner, Baron von, his experiments on electric firing, 113
Edison, T. A., his invention of the phonograph, 36; his carbon transmitter, 40
Edison dynamo-machines, increase of efficiency of, 101
Electric arc, action of the, 101
—— lighting. "Some Points in Electric Lighting," 81
—— railway, the first, 73
Electrical storage batteries, 69
—— transmission and storage of power, the, 56
"Electrical Units of Measurement," 149
Electrical units, 77
Electricity, definition of, 1
"Electricity Applied to Explosive Purposes," 107
—— atmospheric, accidental discharge of mines by, 130
Electro-horticulture, 72
Electromotive force, 2
Errors, sources of, in transmitting telegrams, 13
Exchange system of telephony, 48
Explosives, electricity applied to, 107

Fairy-Orchestra at the Polytechnic Institute, the, 28
Farad unit, 77
Faraday, M., original induction-coil of, 58; his discovery that a closed conductor moving in a magnetic field will induce electric currents, 87
"Faraday," cable-laying steamer, 70
Faure's secondary battery, 76
Fisher, Col. A. à' C., his experiments in connection with the electric firing of submarine mines, 138
Fourier's system of dimensional equations for absolute measurements, 159
Frankland, Dr. E., his statement of the action of secondary batteries, 76
Franklin, B., his experiments on the firing of gunpowder by electricity, 108
Frictional electric machines for firing gunpowder, 114 *et seq.*
Froude, W., 100
Fuzes, electrical, 114 *et seq.*

Gas *versus* electric lighting, 105

Gauss's measurements in terrestrial magnetism, 153
German-silver wires, suitability of, for the bridges of fuzes, 132
Gladstone, Dr. J. H., his statement of the action of secondary batteries, 76
Götzmann. *See* Warrentrap.
Gramme dynamo-electric machine, the, 63, 93
Growth of telegraphy in England, 19
Gun-tubes, electrical, 134
Gutta-percha the best insulator, 7

Hallett's Point reef (Hell-gate, N.Y.) destruction of, 146
Hancock's steam-coach, effect of the introduction of, on turnpike tolls, 26
Hawksley, T., proposer of vote of thanks to lecturers on electricity, 175
Hefner, Alteneck von, his mode of winding the bobbin of dynamo-machines, 64
Helmholtz's confirmation of Faraday's law, 87
Henley, W., his electrical fuze, 119
High-tension fuzes, 128 *et seq.*
Holmes's magneto-electric machine, 60
Hopkinson, Dr. J., his electric hoist, 70; "Some Points in Electric Lighting," 81—Vote of thanks to, 106
———, Dr. E., 73
Hughes, D. E., his type-writer, 14; microphone, 42
Hutchinson, General, his memoir on the explosion of gunpowder, 110
Hydraulic head, analogy of, to electrical current, 82

Insulators, electrical, materials forming, 4
International conference on electrical units, Paris, 1881, 154
Iron and Steel Institute, Dr. Siemens' presidential address before the, 1877, 71
"Ironsides," U.S. ironclad, escape of, from destruction by a submarine mine, 128
Italian war of 1859, electric torpedo defences proposed for the, 138

Jacobi's law of maximum effect of transmitting work by dynamo-machines, 96
Johnson, E. H., his illustration of the phonograph, 37
Joule's thermo-electrical determination of the ohm, 173

Ladd's electrical exploder, 121
Laflin and Rands' electric exploder, 123
Larcom, Capt., his electrical blasting operations at Phœnix Park, 110
Leclanché battery, 3
Lichterfelde electric tramway, the, 73
Light, nature and composition of, 81
Lighting, electric, some points in, 81
Locke, J., 1
Logograph, the, 28
Losses in the dynamo-electric machine, 95

McEvoy, Capt., 143
McKinlay, Sergeant, use of electricity by, for firing guns upon proof, 134
Magnetic field, the, 59
Magnetisation of iron by electric currents, 11
Magneto-electricity, 59
Mapping the bottom of the sea, 8
Markus' electrical exploder, 121
Matheson's combination of mechanical with self-contained electrical arrangements for firing submarine mines, 140, 142
Maxwell, Professor J. Clerk, his dictum as to the reversibility of the dynamo-machine, 63
Measurement of electricity, 150
Méchain and Delambre's geodetic determination of the metre, 161
Mercury unit, the, 154
Meyer's system of multiple telegraphy, 18
"Mho," suggested use of the term, 171
Microphone, 42; employment of the, for detecting the approach of ships to a submarine mine station, 143
Mining, use of electricity in, 145
Morse, S. F. B., his telegraph alphabet and instruments, 12, 53
Multiple telegraphy, systems of Meyer and Baudot, 18

Oersted's discovery of electro-magnets, 87.
Ohm, 99; origin of the name, 154; measurement of the, 169
Ordnance Select Committee's inquiry into the use of electricity for exploding gunpowder, 113

Pacinotti's dynamo-electric machine, 64, 92
Paris Electric Exhibition, 1881, electric railway at the, 73
Pasley, Sir C., his early experiments on blasting by electricity, 108; ditto, destruction of the "Royal George," 109
Peiho forts, proposal to use electric firing at the operations against the, 137
Perry, J. *See* Ayrton.
Phonograph, the, 36
Photophone, the, 45
Pixii's magneto-electric machine, 60
Planté, G., his secondary battery of 1860, 176
Platinum silver wires for the bridges of fuzes, 132
Poggendorff's discovery of the power of bichromate of potash, 3
Polytechnic Institution, the "Fairy Orchestra" at, 28
Portrush and Bush Mills electric tramway, 73
Post-office telegraphs, number of batteries used in the department, 4; number of messages transmitted by, 17; growth of wire of, 17
Power. "The Electrical Transmission and Storage of Power," 56
Preece, W. H. "The Progress of Telegraphy," 1—Vote of thanks to, 22
Press telegrams, mode of distributing, 17.
Priestley, Dr., his experiments on the firing of gunpowder by electricity, 108

Quadruplex telegraphy, 16

Radiation from heated bodies, effects of, 81
Railways, development of, influence of, on the development of telegraphs, 21, 24; electric ditto, 73
Rands. *See* Laflin.
Rayleigh, Lord, and Mrs. Sidgwick, their measurement of the ohm, 155 *et seq.*
Receivers and transmitters (telephonic), definition of, 27; Edison's, 43
Reiss, P., his telephone of 1862, 32
Reproduction of sound previous to telephonic days limited to similar notes, 27
Resistance-measurer of Sir W. Siemens 172
Reversed undulatory currents, illustration of, 39
Round Down Cliff, Dover, blasting of the, by electricity, 109, 110
"Royal George," operations for blowing up the wreck of the, 109
Ruhmkorff coil, 86; use of, in electrical firing, 111 *et seq.*
————'s experiments on electrical firing, 112
Russo-Turkish war, use of torpedoes in the, 144

Sand-batteries for exploding fuzes, 127
Savare's arrangement of branch- or fork-circuits for utilizing a succession of currents of high tension, 111, 117
Scott, Gen. H. Y. D., experiments of, on electrical firing, 120
Secondary batteries, 69, 76
Seebeck's thermo-battery, 57
Selenium, peculiar properties of, 45
Sellon's secondary battery, 76
Shaw, M., his fuze for electrical firing, 114
Shoolbred, J. N., 98
Sidgwick, Mrs. *See* Rayleigh, Lord.
Siemens high-tension dynamo-electric machine for firing fuzes, 125; Siemens unit, 154
——— and Halske's electrical exploders, 121
——— Brothers, Messrs., arc lamps of, 103
———, A., 73

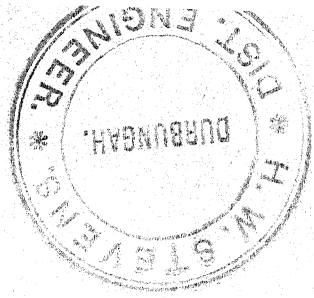
Siemens, C. W., "The Electrical Transmission and Storage of Power," 56—Vote of thanks to, 80
———, Werner, his discovery of the principle of the dynamo-electric machine, 62
Signals, electric, mode of interpreting, 9
Single-needle instrument, 12
Smith, Willoughby, his discovery of selenium, 45
Solar second, means of obtaining the, 64
Sound, reading of electric signals by, 11
—— Reproduction of by telephones, 26
Southby's mode of using a secondary coil for electrical firing, 117
Statham and Brunton's electric fuze, 115
Stephenson, R., 1
Storage, electrical, 69
Striedinger, J. H., his work in furthering electrical blasting, 143, 147
Submarine mines, use of, in warfare, 138 *et seq.*
Submarine telegraph network, the, 7

Telegraphy, the progress of, 1
Telephone-exchanges, 48
"Telephones," 26
Telephony held to be a branch of telegraphy, 26
Theory of the dynamo-electric machine, 88
Thermo-battery, the, 57
Thomson, Sir W., "Electrical Units of Measurement," 149; his wire-sounder on board the "Faraday," 70; his suggestions as to the electric transmission of power, 72; vote of thanks, 174
Time, unit of, determination of the, 165
Time-guns, electrical, 135
Torpedoes, electric, use of in warfare, 136 *et seq.*
Traill, W. A., engineer of the Portrush and Bush Mills tramway, 73
Tramways, electric, 73
Transmission of power by electricity, early researches on the, 71
Transmitters (telephonic), Bell's, 38; Edison's, 40; Blake's, 47
Tresca, H., his communication to the French Academy of Sciences of Marcel Deprez's experiments on the electric transmission of power, 72
Tribe, —, his statement of the action of secondary batteries, 76
Tuning-fork, the, as a time-standard, 162

Underground *versus* overground telegraph wires, 6
United Telephone Company, 52
Units, electrical, 82
Universal gravitation unit of matter, 157, 161

Varley, S. A., 94
Verdu, Col., his experiments of 1853 on electrical firing, 112 *et seq.*
Vibration, telephonic, 33
Volkman's secondary battery, 76
Volt unit, 77
Volta's attempts to obtain and transmit power by electricity, 57
Voltaic batteries alone eligible for electrical firing, 126

War-ships, electrical firing in, 135
Ward, Col., his advocacy of, and experiments on, electric firing, 111 *et seq.*
Warrentrap and Götzmann's experiments on electrical firing, 113
Watt unit, 78, 82
Watt-meter, 79
Weber's measurements in terrestrial magnetism, 153
Wheatstone, Sir C., double-needle instrument of, 10; his automatic working system, 16; his "Fairy Orchestra," 28; his discovery of the principle of the dynamo-electric machine, 162
Wilde's magneto-electric machine, 61
Wires for electrical conduction, best materials for, 5



LONDON:
PRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
STAMFORD STREET AND CHARING CROSS.